TRIUMF
CANADA'S NATIONAL LABORATORY FOR PARTICLE AND NUCLEAR PHYSICS
Owned and operated as a joint venture by a consortium of Canadian universities via a contribution through the National Research Council Canada

Highlights from the ISAC Science Program

Greg Hackman, TRIUMF

ISOLDE Workshop and Users' Group Meeting

2009-11-19 14h00-14h30

LABORATOIRE NATIONAL CANADIEN POUR LA RECHERCHE EN PHYSIQUE NUCLÉAIRE ET EN PHYSIQUE DES PARTICULES

Propriété d'un consortium d'universités canadiennes, géré en co-entreprise à partir d'une contribution administrée par le Conseil national de recherches Canada

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PRELIMINARY

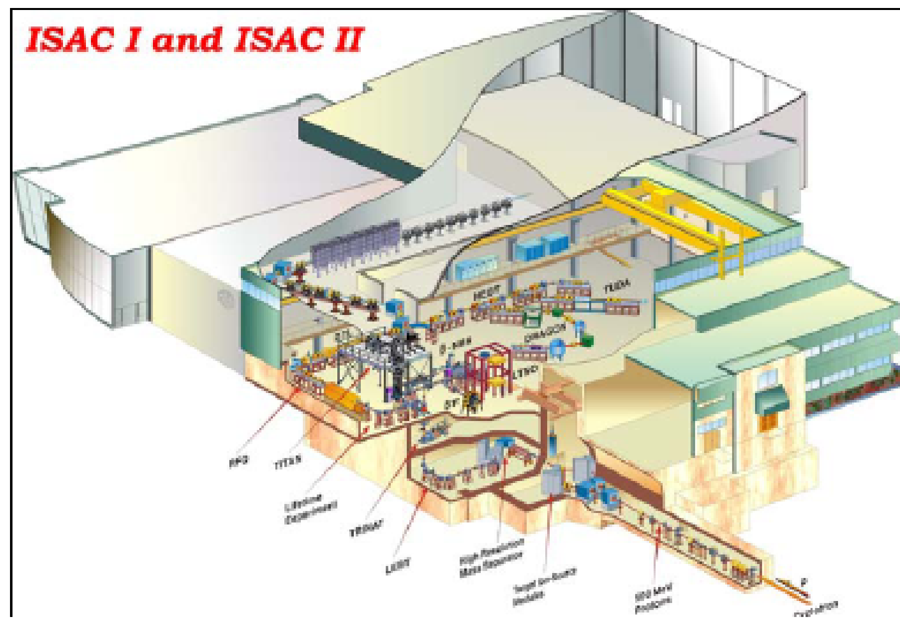
TRIUMF AND ISAC BACKGROUND

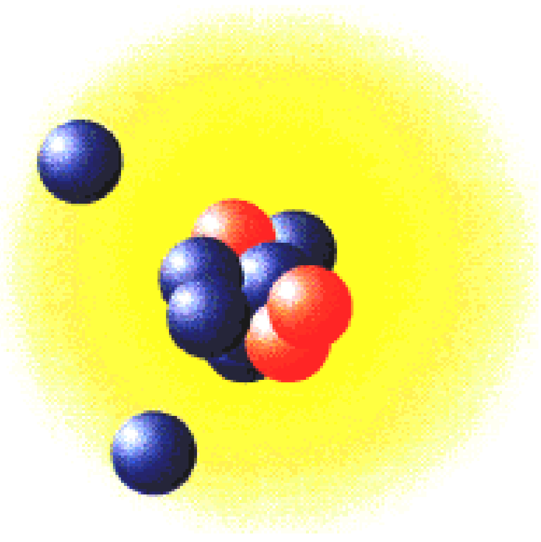
TRIUMF-ISAC

Up to 100 μA, 500 MeV proton beams from the TRIUMF cyclotron produce high-intensity secondary beams of radioactive isotopes by the ISOL technique.

- decay properties of these isotopes are studied by a variety for experimental techniques

- the isotopes can also be accelerated up to energies of 6 MeV/u for reaction studies





HALO NUCLEI: Li AND Be

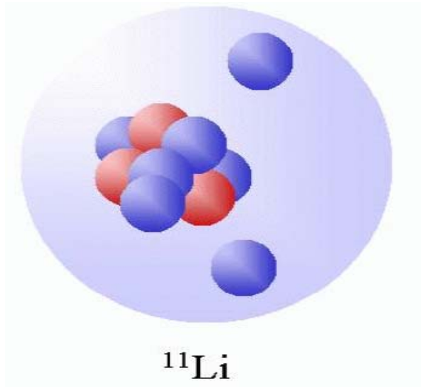
Selected Recent Publications on Halo Nuclei Experiments at TRIUMF-ISAC

- ^{11}Li β-n-DSAM : F. Sarazin *et al.*, Phys. Rev. C 70, 031302R (2004), and C. Mattoon et al., PRC 80, 034318 (2009) [*CSM*]
- ^{11}Li β-n: Y. Hirayama *et al.*, Phys. Lett. B611, 239 (2005) [*Osaka*]
- ^{11}Li charge radius: R. Sanchez *et al.*, PRL 96, 033002 (2006) [*GSI, U. Tübignen*]
- ^{11}Li β-charged particle: R. Raabe *et al.*, PRL 101, 212501 (2008) [*K.U.Leuven*]
- ^{11}Li two-neutron transfer (p,t): Tanihata, Savajols *et al*, PRL 100, 192502 (2008) [*GANIL,Osaka*]
- ^{9,11}Li mass: M. Smith *et al.*, PRL 101, 202501 (2008)
- ^{8}He mass: V. Rykov *et al.*, PRL 101, 202301 (2008)
- ^{11}Be mass: R. Ringle *et al.*, PLB 675, 170 (2009)

Study of halo effects in the Scattering of ^{11}Li with heavy targets at energies around the Coulomb barrier @ ISAC II

CSIC Madrid, U Sevilla – U. Huelva et al

July 2008 and Oct 2008



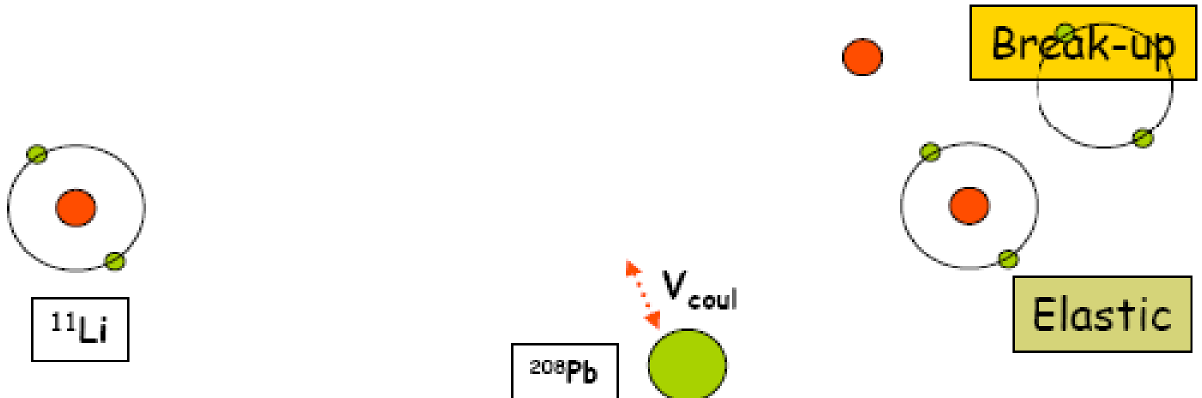
Reaction properties at near-barrier energies:

→ Strong absorption in elastic channel

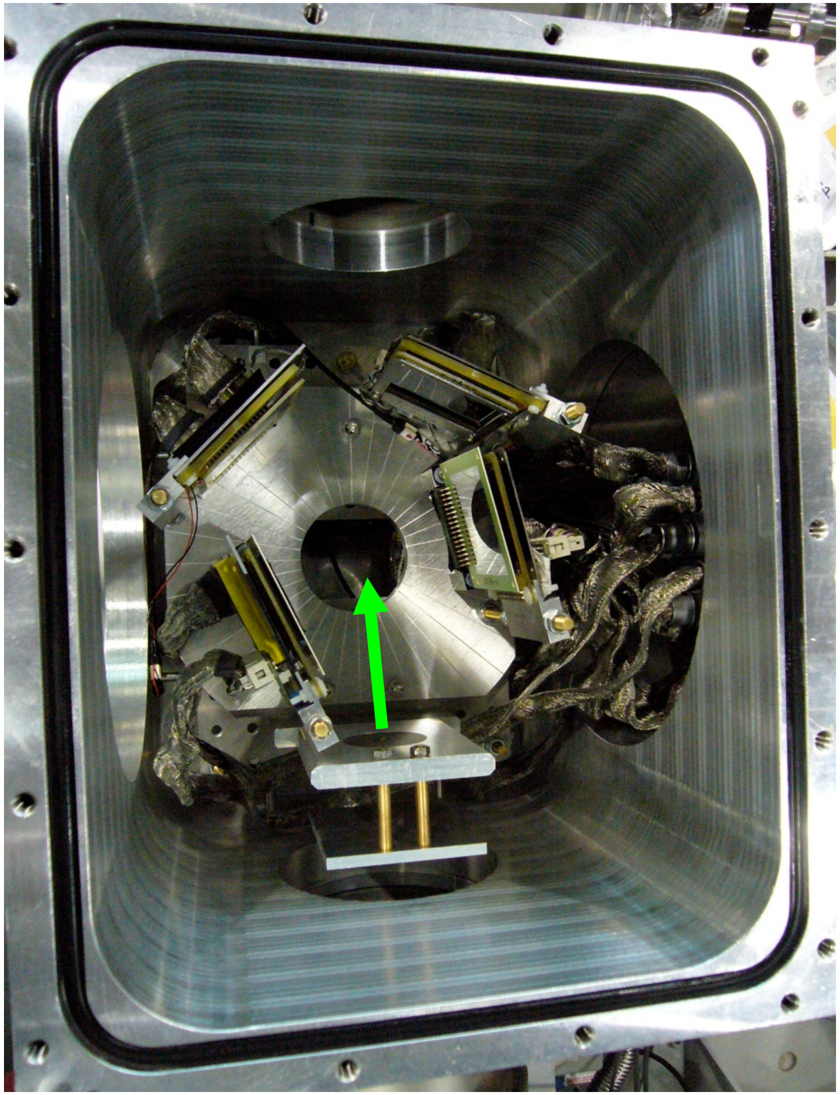
→ Large cross section for fragmentation

→ They are easily polarizable:

- In the scattering process the forces between target and core/ halo are different → distortion effects → **e.g. Coulomb dipole polarizability**



Set-up



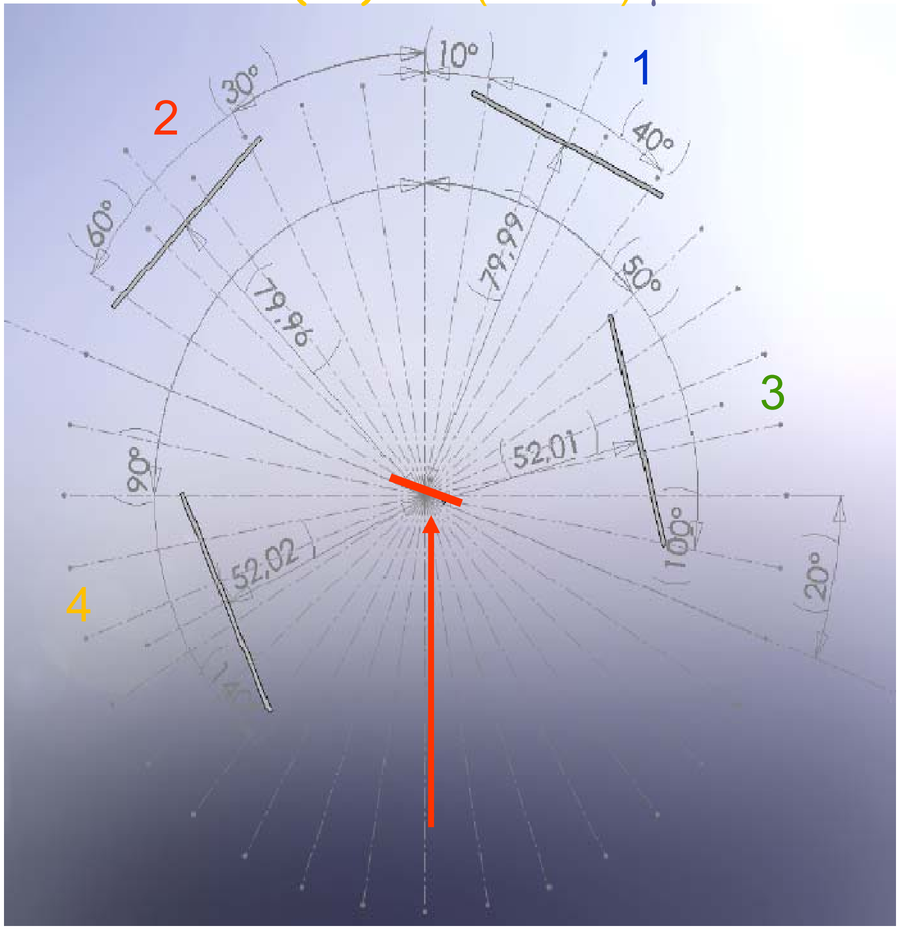
4 Telescopes

10°-40° 40 (16x16) +500 μm

30°-60° 40 (16x16) +500 μm

50°-100° 20(16)+60 (16x16) μm

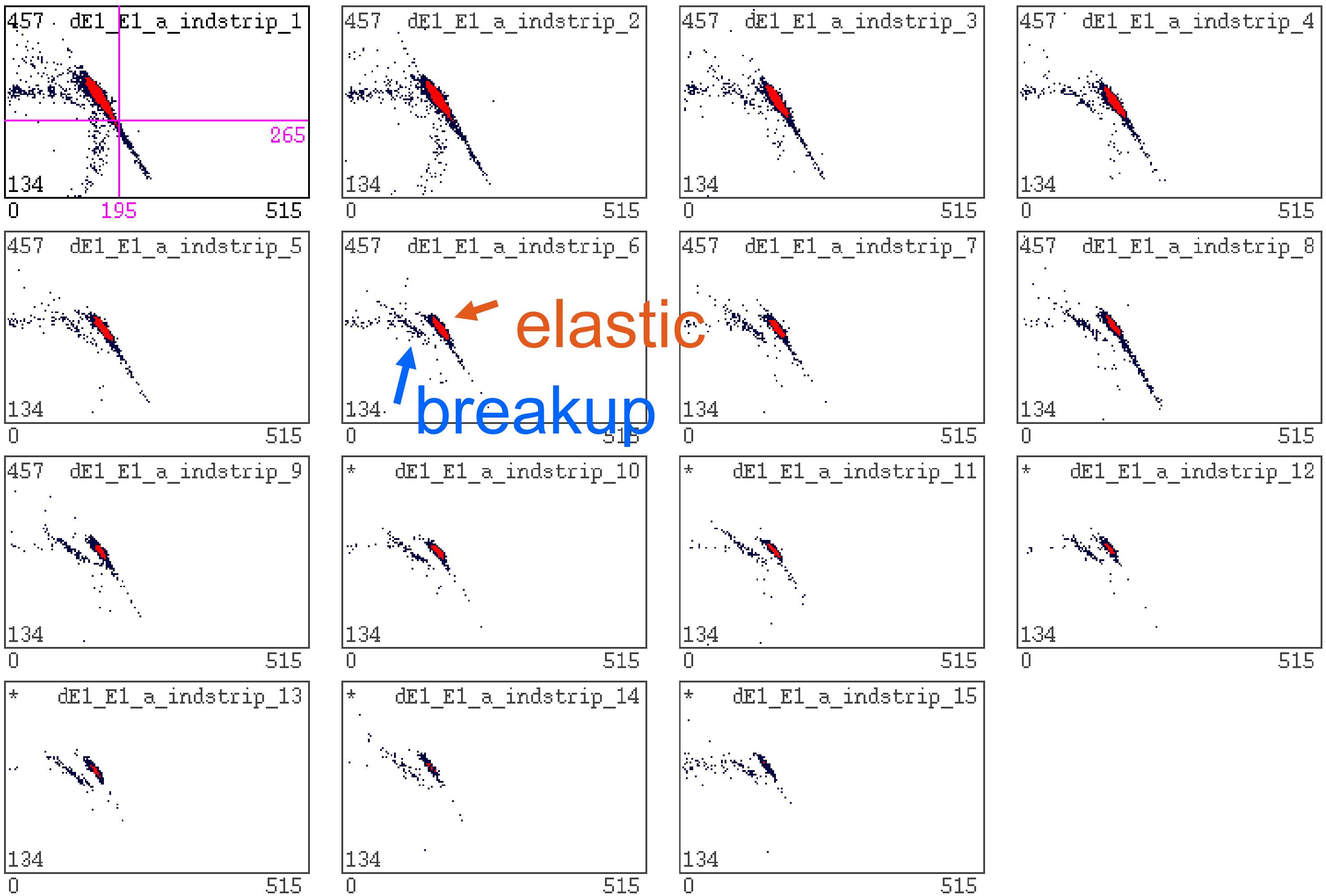
90°-140° 20(16)+60 (16x16) μm



2.2 MeV/u ^{11}Li on ^{208}Pb

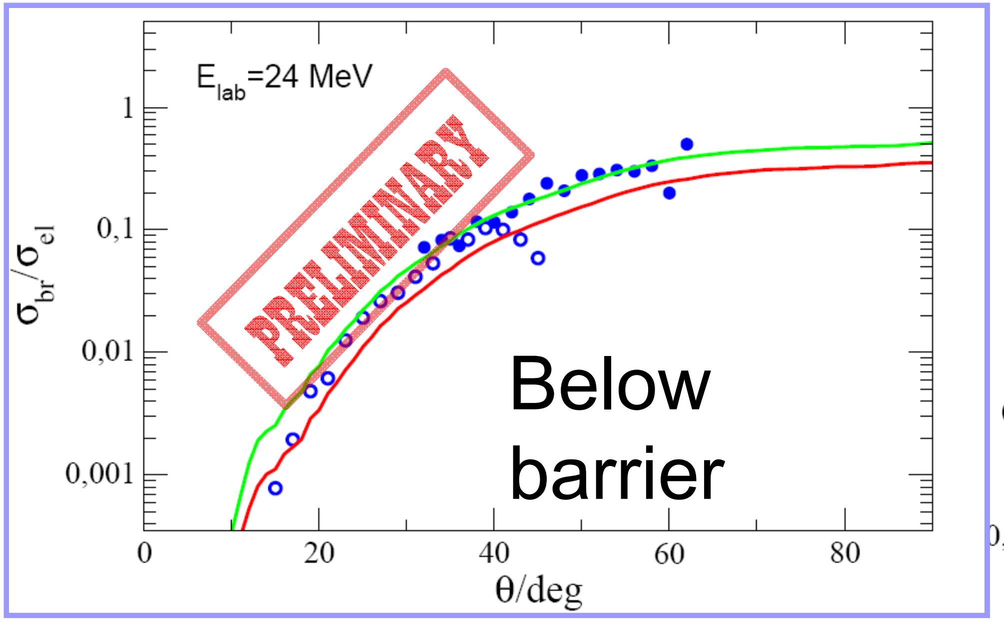
Forward Strip detector θ = 15-40 deg

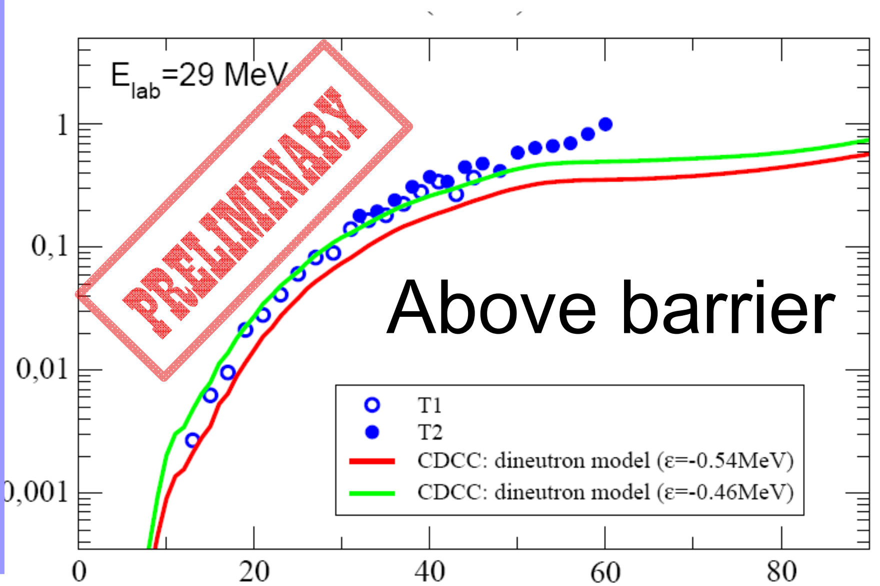
^{11}Li 6000/s Oct 2008

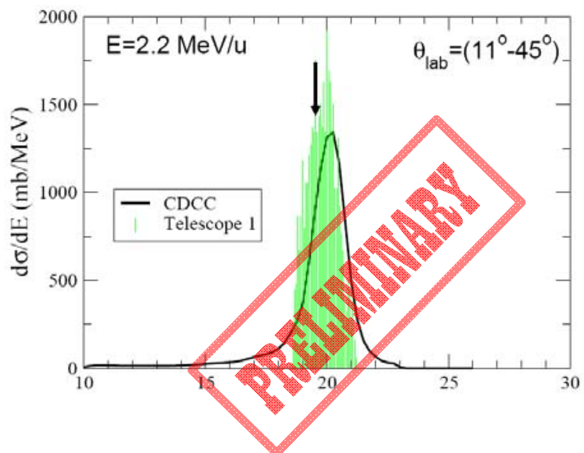


$^{11}Li + ^{208}Pb$

The Comparison of the breakup/elastic cross sections to determine which of the 3-body models of ^{11}Li is more realistic



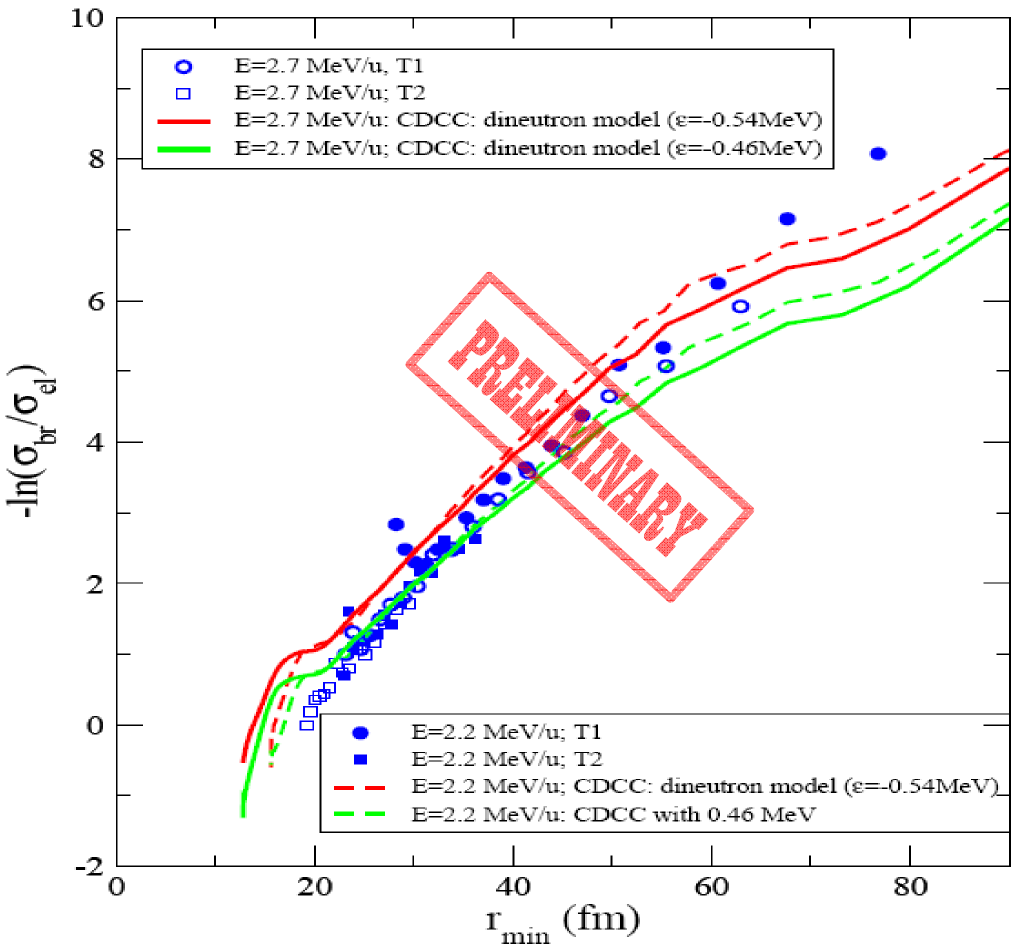




- The energy distribution of the breakup products indicates that the dominant process at forward angle is DIRECT BREAK UP
- CDCC calculation using εb=0.46 MeV correponding to S2n = 0.37 MeV

-Preliminary interpretation of data:

-Plot vs distance of closest approach



All data fall on a straight line !

✓ A linear behaviour of $\ln(\sigma_{br}/\sigma_{el})$ versus r_{min} indicates in a semi-classical approach that the dominant interaction at large distance is the Dipole interaction.

$$T_{colision} = r_{min}/v$$

✓ The slope is proportional to the excitation energy of the relevant states of the system (^9Li + 2n)

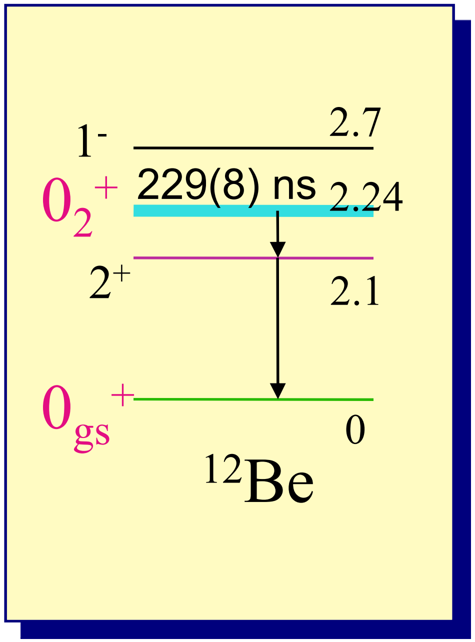
$$Ex = \lambda\hbar v = 1.2\text{-}1.3 \text{ MeV}$$

✓ Small slope(λ) $\Rightarrow$ relevance of states of low excitation energy

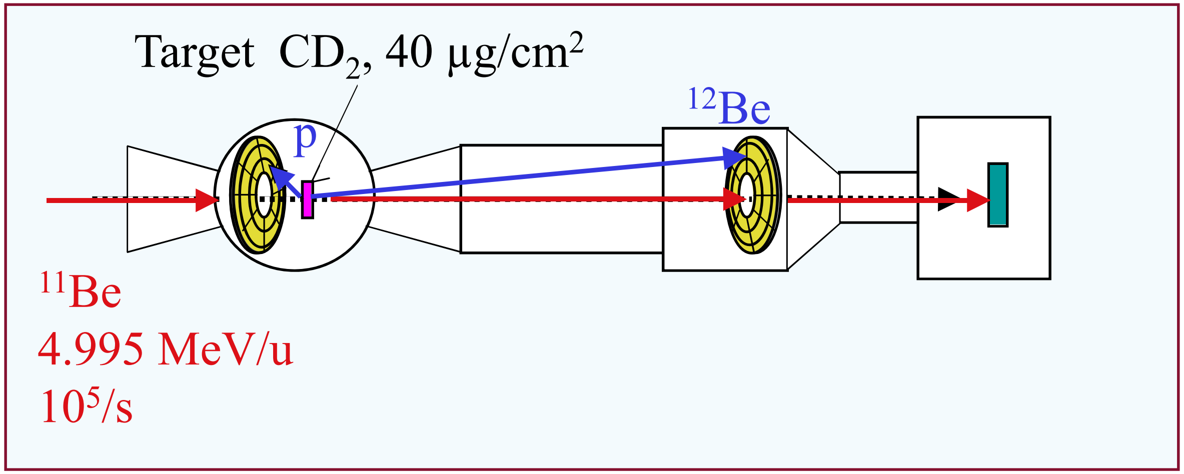
✓ The value of $\ln(\sigma_{br}/\sigma_{el})$ at a certain r_{min} is related to the B(E1) to the revelant BU states

✓ Large BU cross section $\Rightarrow$ Large B(E1) to states of low excitation energy

Investigation of Halo Features and Structure of Levels in ^{12}Be



- Goal: determine single-particle structure of excited 0^+ states
- $^{11}Be(d,p)$
- Si reactant detectors, inorganic beam counter, TIGRESS electronics



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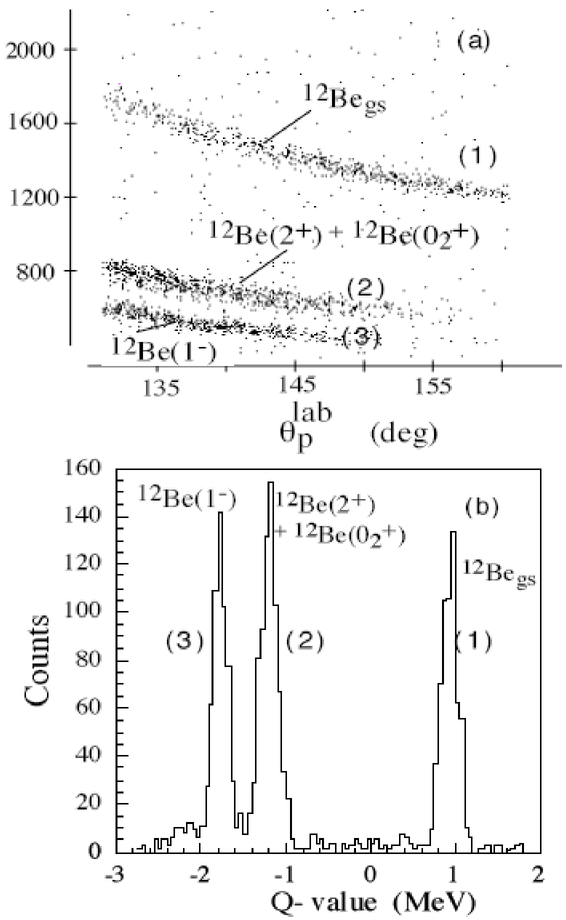
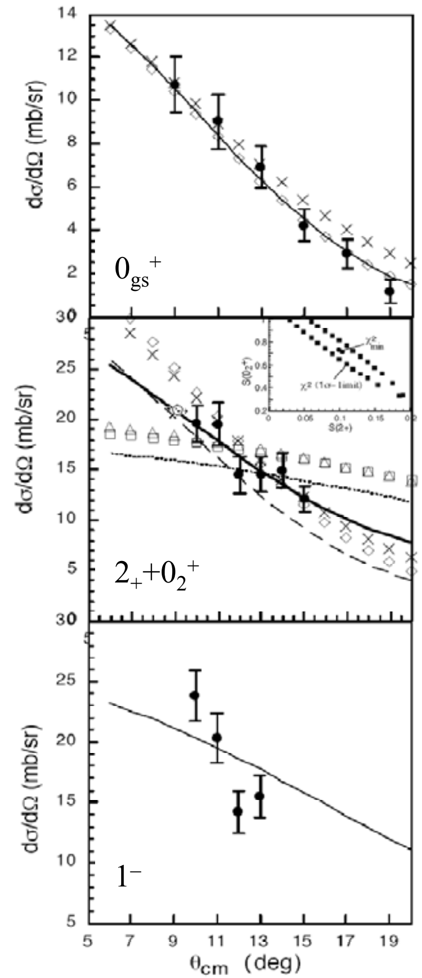


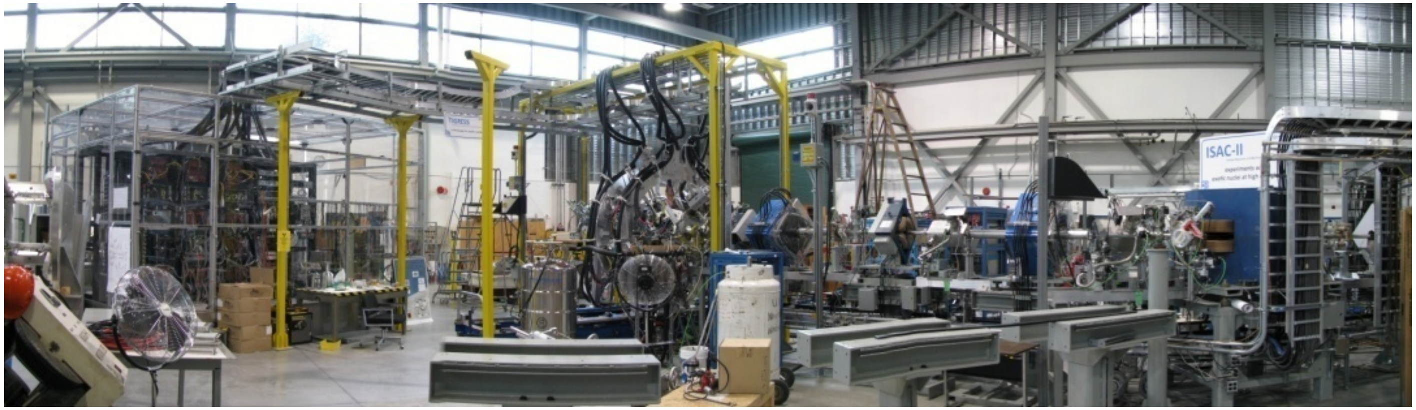


- Left: Kinematic curves, Q-Value spectrum
- Middle: angular distributions, fits
  - For $2^+ + 0_2^+$, d and s minimized simultaneously

Spectroscopic factors:

- gs: 0.28(0.07)
- 0_2+: 0.73 $^{+0.27}_{-0.40}$

R. Kanungo *et al.*, PLB, in press



A~20-30 GAMMA-TAGGED SCATTERING

Structure of ^{26}Na

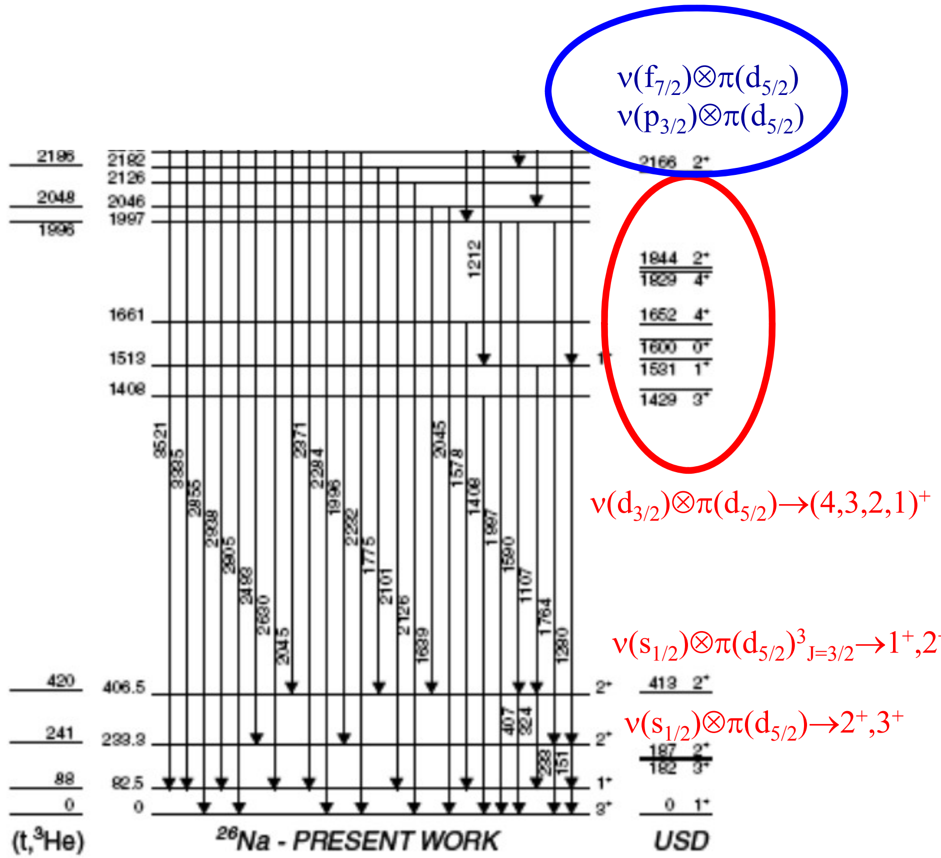
Experiment: ^{25}Na(d,p) ^{26}Na in inverse kinematics with a beam energy of 4.995 MeV/u

W.N. Catford, G. Wilson et al.

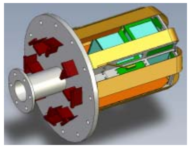
- Use gamma tagging to identify specific states
  - (as with T-REX, Wimmer *et al.*)

Part of a larger campaign [*Surrey*]

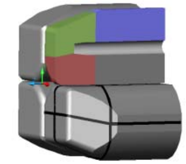
- Structure of ^{26}Na
  - $\nu d_{3/2} \otimes \pi d_{5/2}$ quartet
- Structure of ^{28}Na
  - negative intruders
- ^{24}Na(d,p)^{25}Na
  - IAS to ^{24}Al(p,γ)^{25}Si *rp*-process resonances

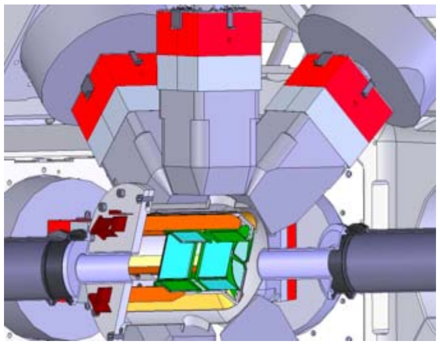


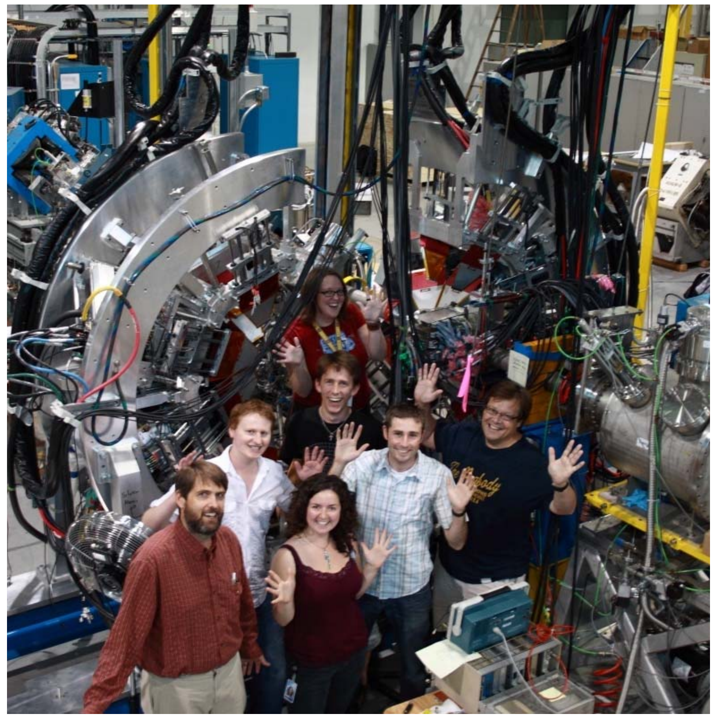
S. L. Tabor, *et al.*, PRC 73, 044321 (2006) ^{14}C(^{14}C,d)

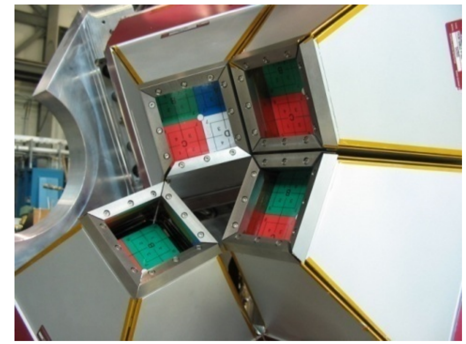


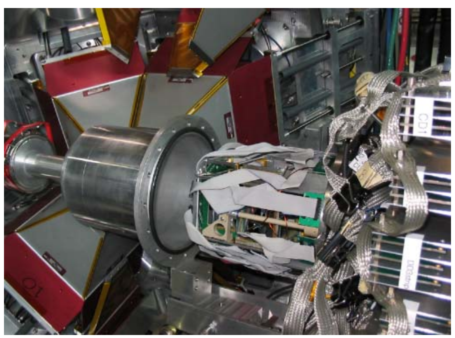
SHARC Silicon barrel plus TIGRESS germanium array

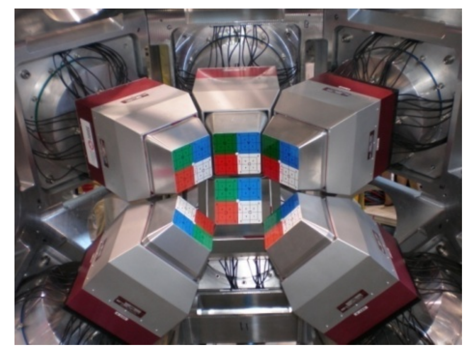


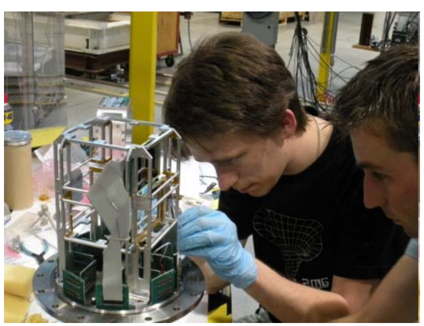


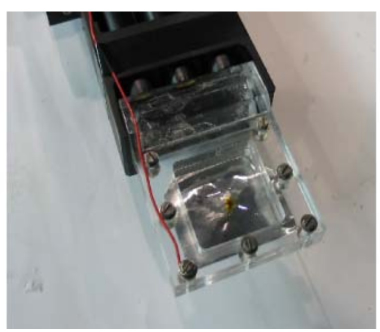


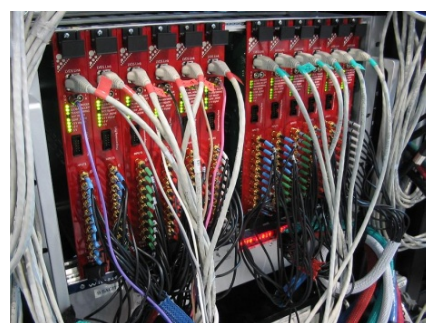


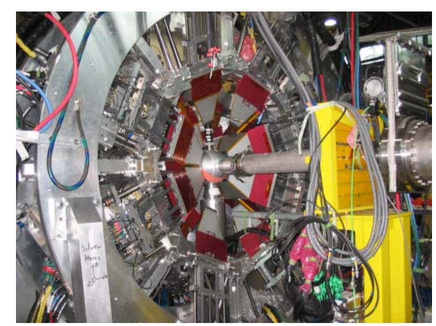


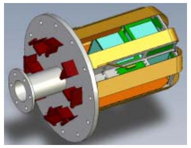












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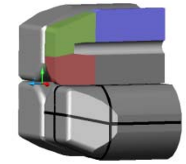
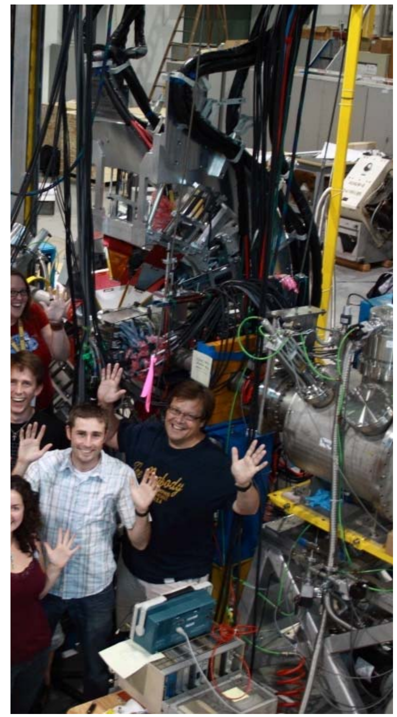
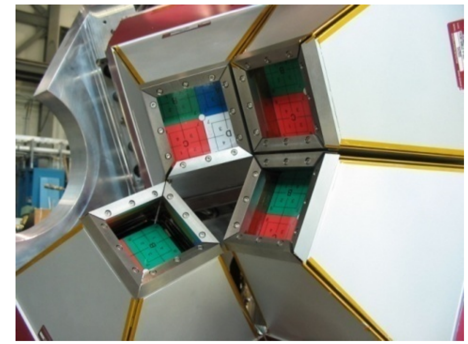
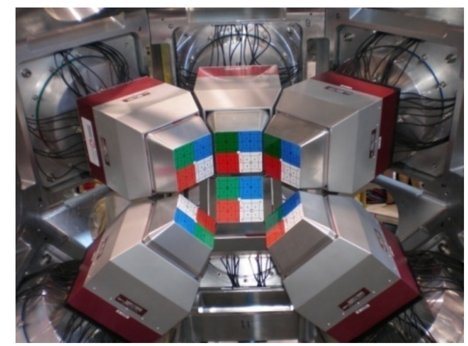


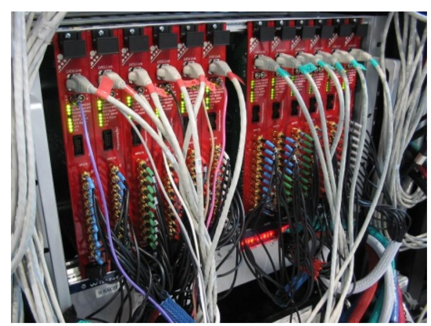
Triumf-Isac Gamma-Ray Escape Suppressed Spectrometer

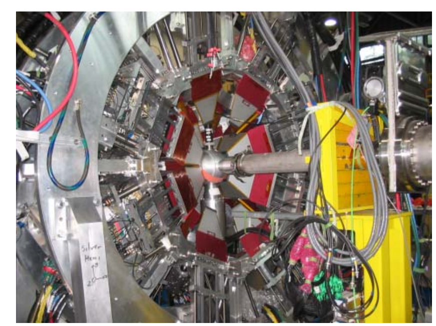
- All-Canadian
- Up to 16 units of:
    - 4-crystal “clover”
        - 8 outer segments each
    - Retractable suppressors
- Close-packing or high-suppression with a turn of a screw (actually, 80 screws)
- Readout by 960 100-MHz 14-bit flash-ADC’s w/ combined trigger and data serial uplink
    - Users compelled to use this for “auxilliary” detectors

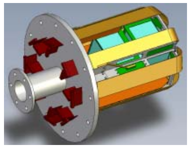




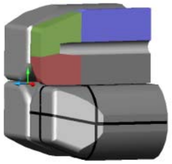


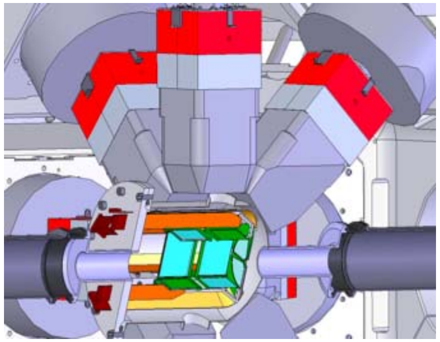


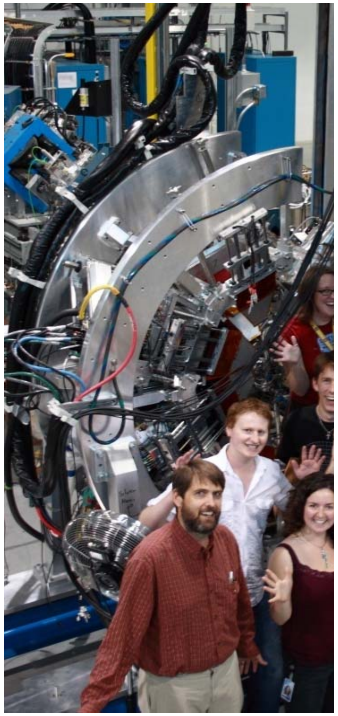


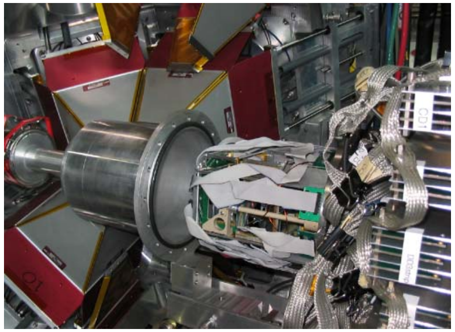


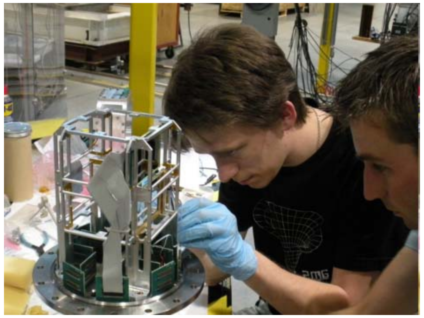
SHARC Silicon barrel plus TIGRESS germanium array

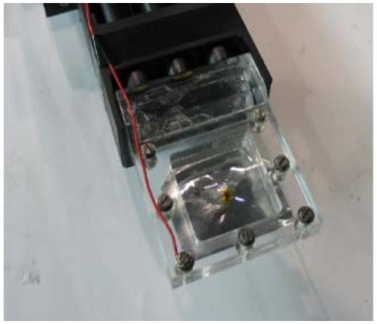










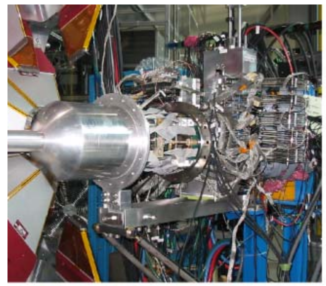


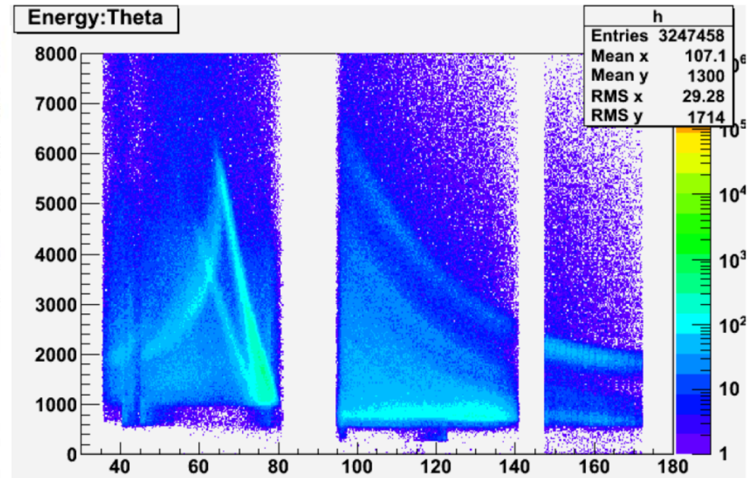
Silicon Highly segmented Array for Reactions and Coulex

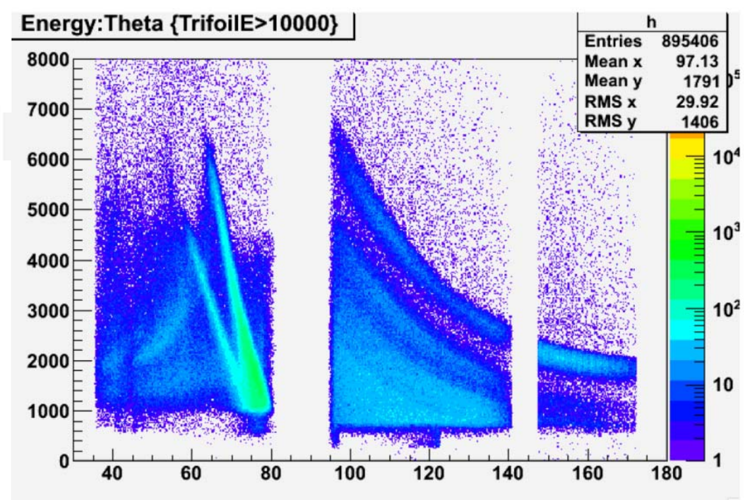
- Mostly not Canadian
- Born out of Colorado School of Mines workshop on Si aux dets for TIGRESS, Feb 2006
- Up to 2x4 Quad-sector CD's and 8 DSSDs
  - E-dE or simple E configs available
- Major capital investment via University of York – C.Aa.Diget, S. Fox, B. Fulton
- Labour etc. from TRIUMF, CSM, Manchester, Louisiana State University
- Digitzers SMU (R. Austin)

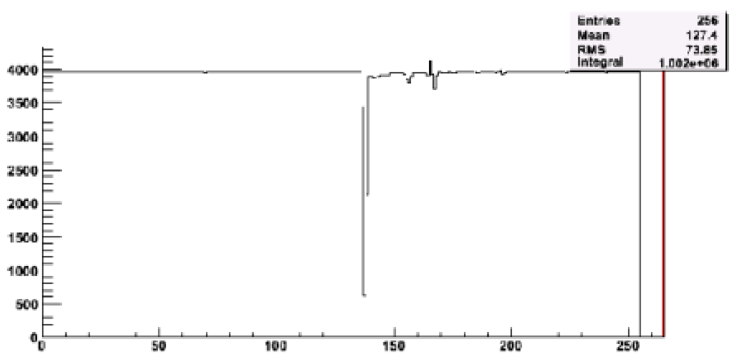
TRIFOIL for Tagging of Projectile-Like Events

- N. Orr, Caen
- Downstream 10 μm plastic scintillator
- 3 PMTs
- 30 μm Al foil to stop fusion-evaporation residues
- Multiplicity 2 for ID of projectile-like HI
- Digitize Fast-NIM logic output in TIG10

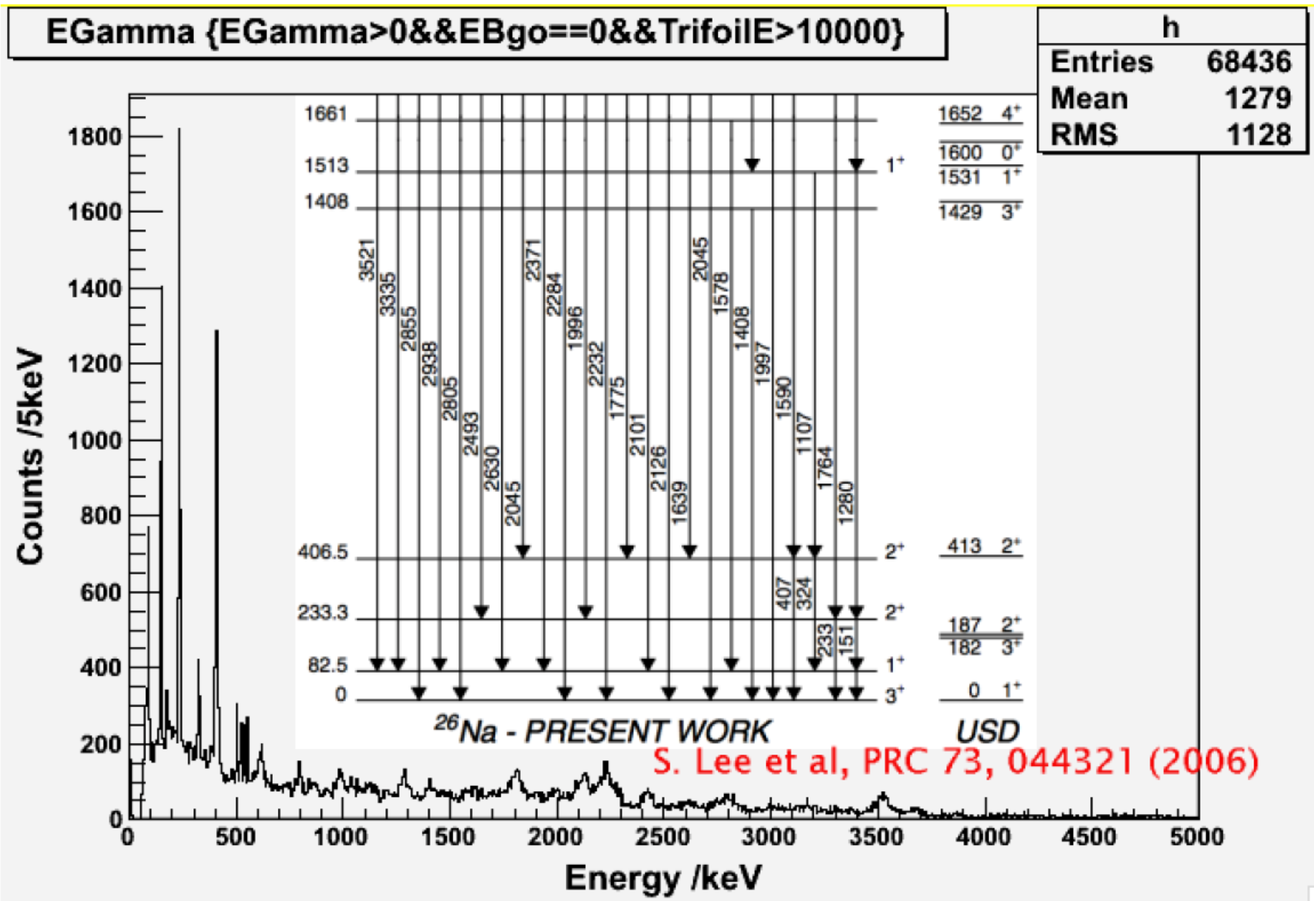






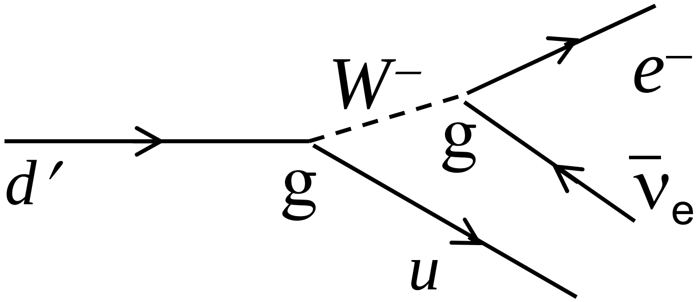


Just-Offline Gamma Spectra



Analysis underway

- Beam limited by Trifoil to 10^6/s
- Team went home happy
- Expect some good results soon



HIGH-PRECISION LIFETIME AND BRANCHING RATIO MEASUREMENTS: ^{19}Ne, ^{26m}Al

Physics justification:

$$\frac{d^4\Gamma}{dE_e d\Omega_e d\Omega_\nu} \propto 1 + a_{\beta\nu}\frac{\vec{p_e}\cdot\vec{p_\nu}}{E_e E_\nu} + b_F\frac{m_e}{E_e} + \frac{\langle\vec{J}\rangle}{J}\cdot\left[A_\beta\frac{\vec{p_e}}{E_e} + B_\nu\frac{\vec{p_\nu}}{E_\nu} + D\frac{\vec{p_e}\times\vec{p_\nu}}{E_e E_\nu}\right]$$

Beta-neutrino correlation

Fierz interference (Scalar interaction)

Madame Wu's asymmetry term

$$\mathcal{F}t = ft(1+\delta_{R'})(1+\delta_{NS}-\delta_C) = \frac{K}{2G_V^2(1+\Delta_R)} = \text{constant}$$

Q-Value, Lifetime, Branching Ratio Measurements

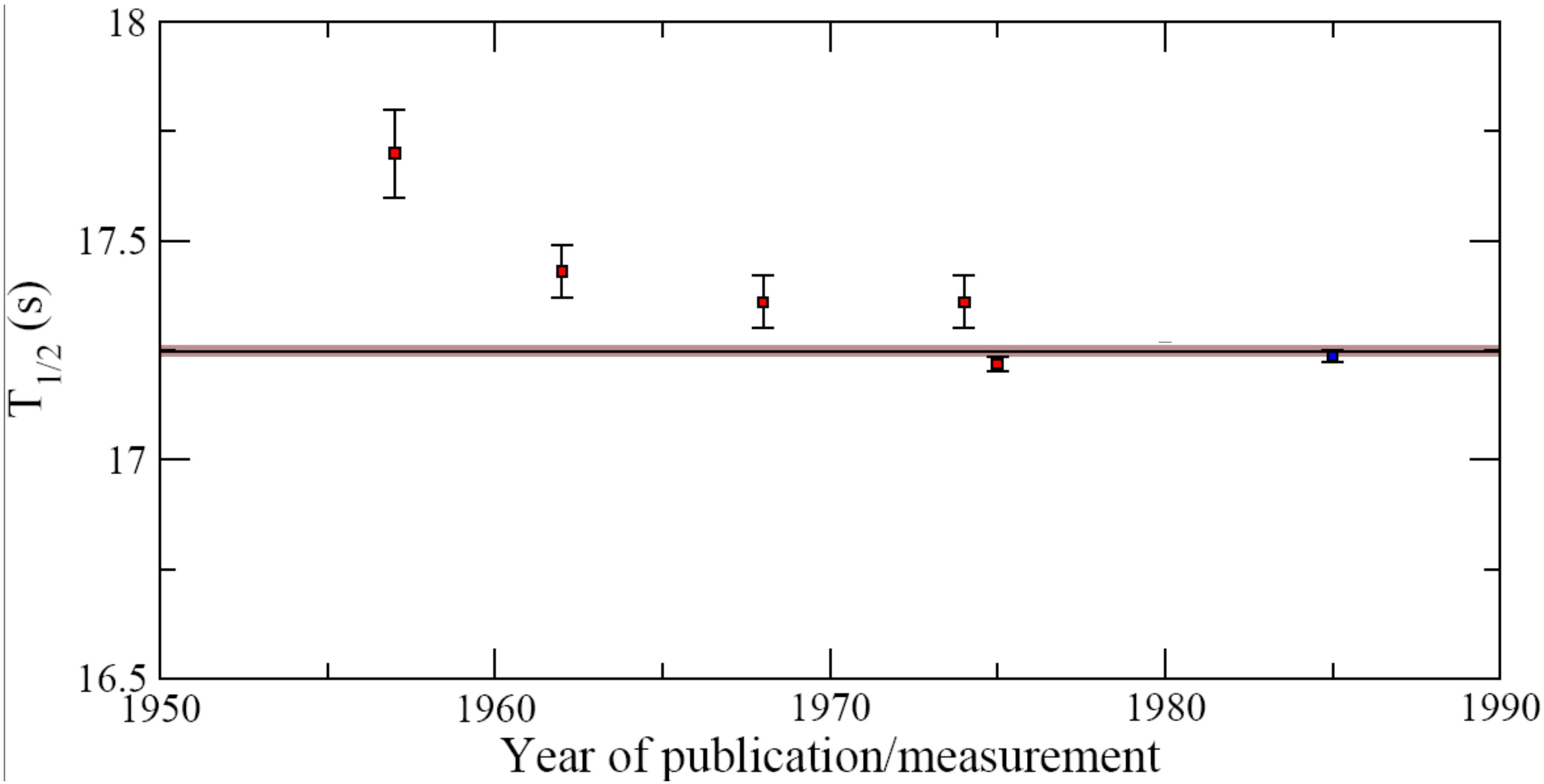
Calculated corrections (~1%) (nucleus dependent)

Inner radiative correction (~2.4%) (nucleus independent)

CVC Hypothesis

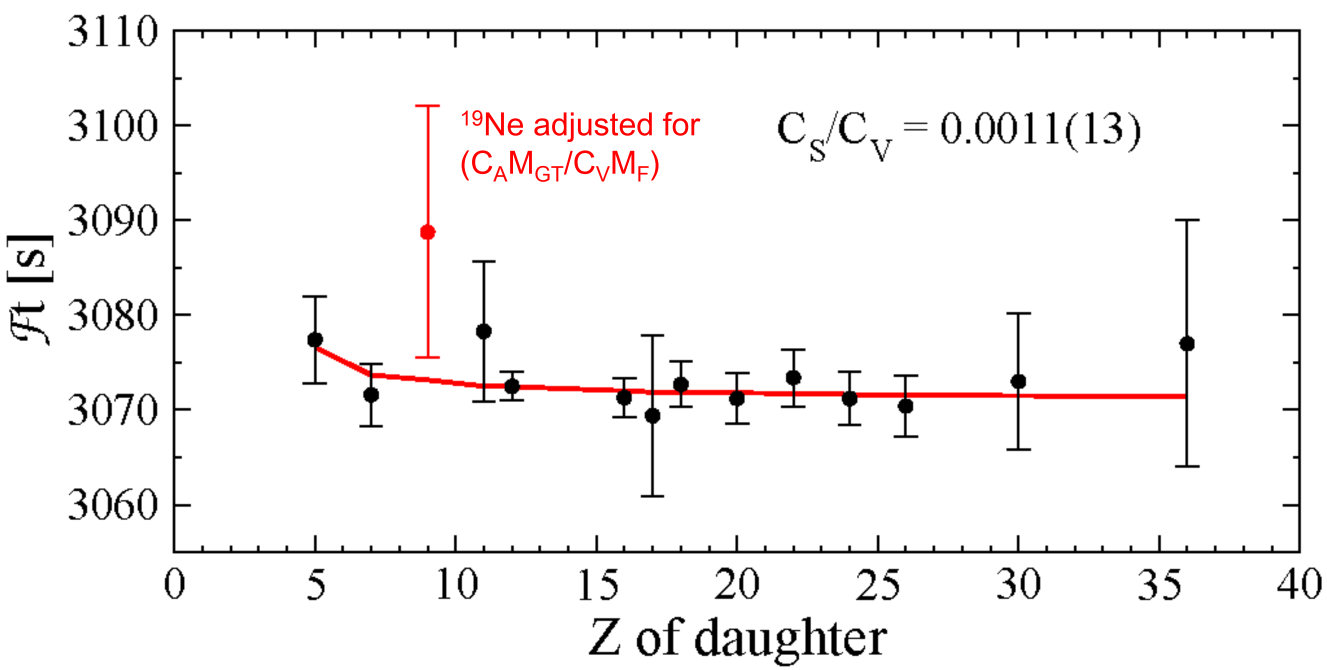
^{19}Ne β decay has issues

- Time-dependent lifetime



^{19}Ne β decay has issues

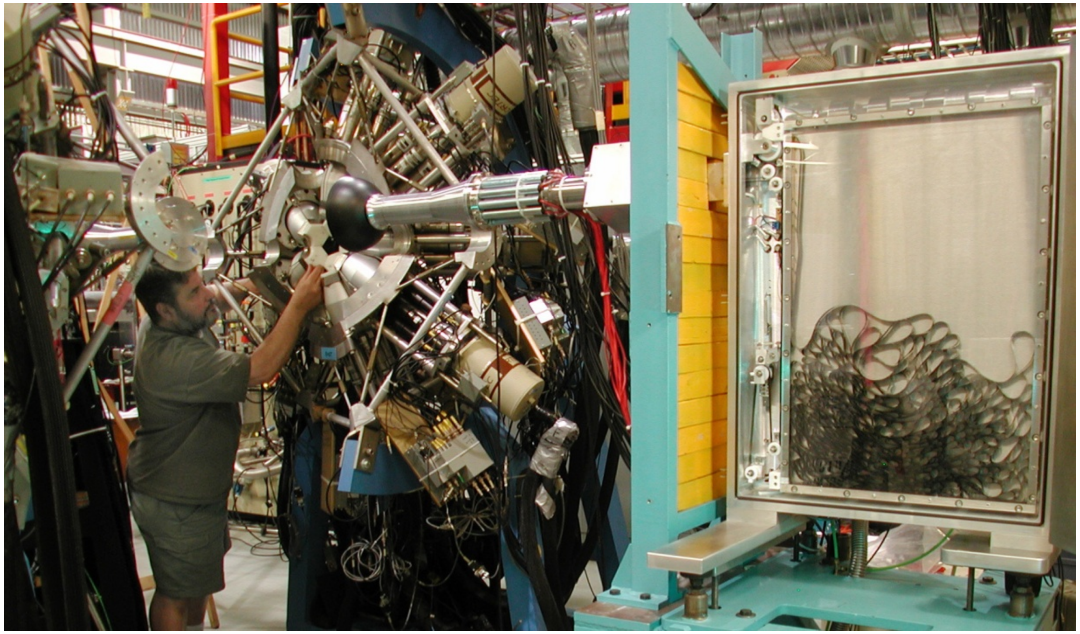
- $\mathcal{F}t(^{19}Ne)$ uncertainty 0.2%, dominated by half-life
- If improved:
  - can be a good data point to constrain Cs/Cv
  - Change by 2σ could bring unpublished (thesis) ^{19}Ne A_β measurements in line with Standard Model

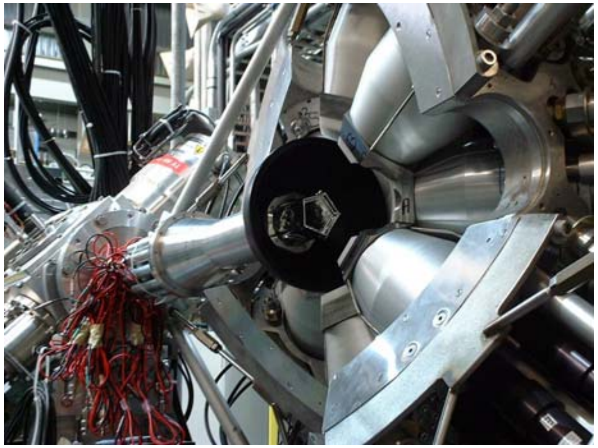


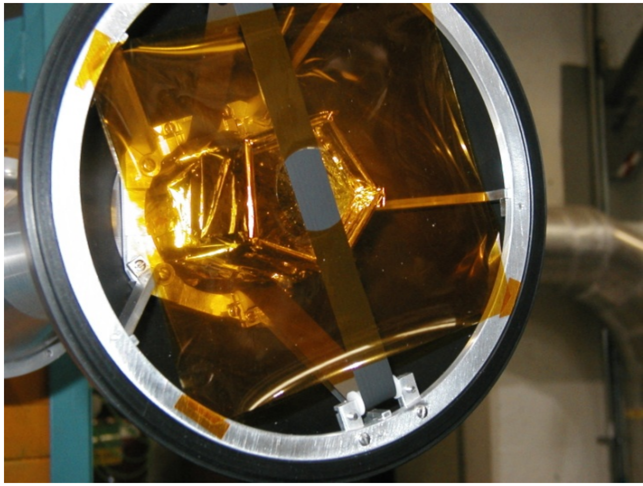
TRIUMF

Use the 8π

- 20 25% HPGe w/ Suppressors
- Endless loop moving tape system (LSU)
  - Programmable states (beam on/off, tape move, trigger veto)
- Inner plastic scintillator array,
- Options: Si(Li), BaF_2
- For ^{19}Ne:
  - Plastics for lifetime
  - HPGe for branching ratio



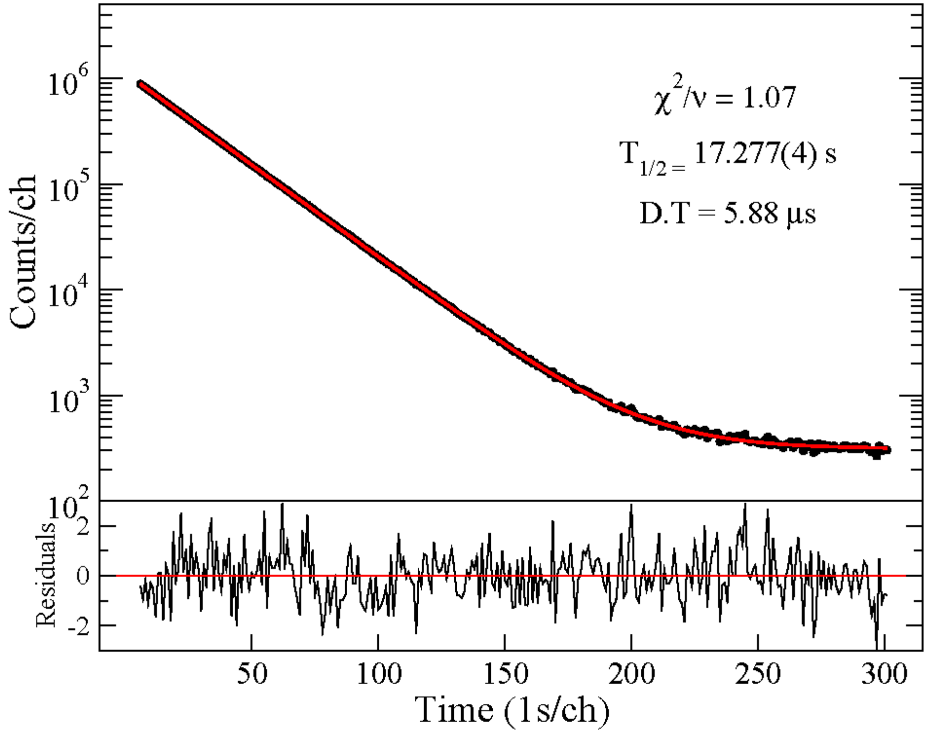




Measurements done with 8π spectrometer

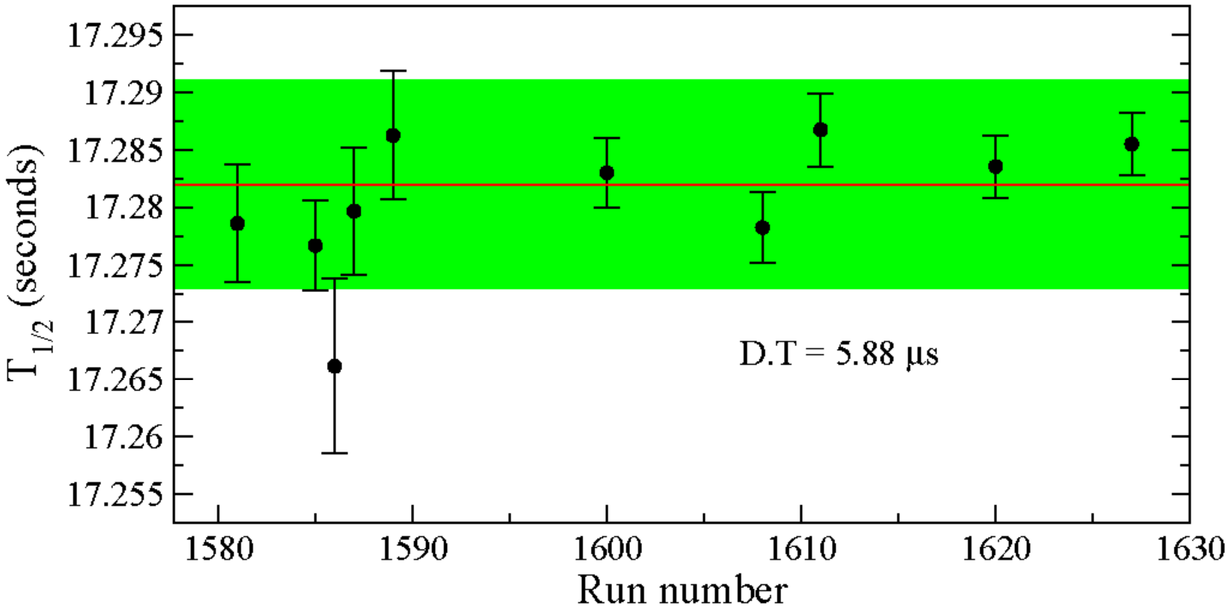
Half-life measurement

- Taken data in both MCS mode and the 'regular' mode at 8π.
- Self-imposed dead times in the range from $2 - 20\mu s$.
- Rates kept at around 1-3 kHz per detector.
- Varied lots of parameters over 30+ hours of data acquisition.



Preliminary results for the half-life

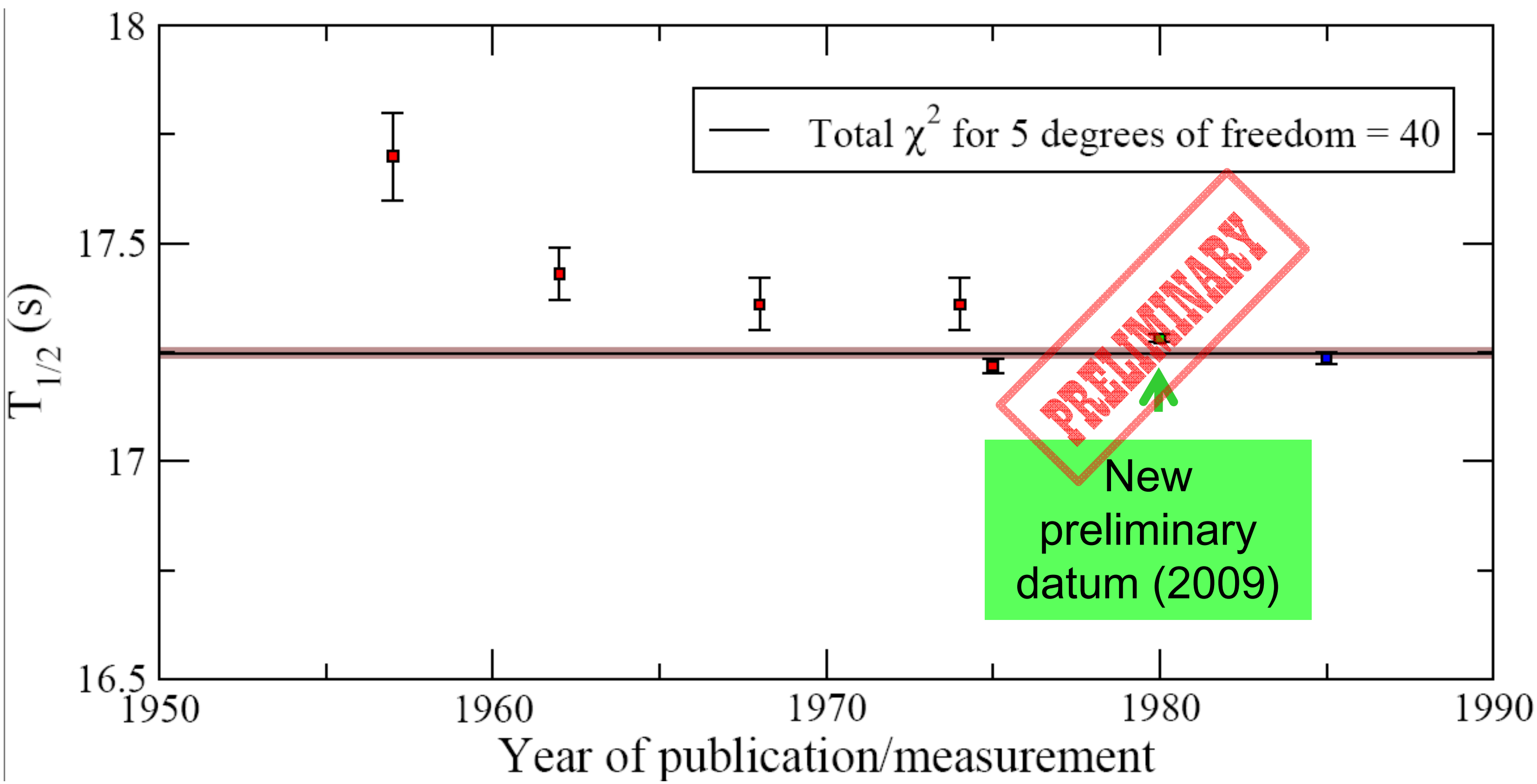
- An example with the 6μs deadtime case



- Already acheived a factor of 2 improvement compared to the last published value
- We observe a 4σ deviation
- Ongoing Analysis..

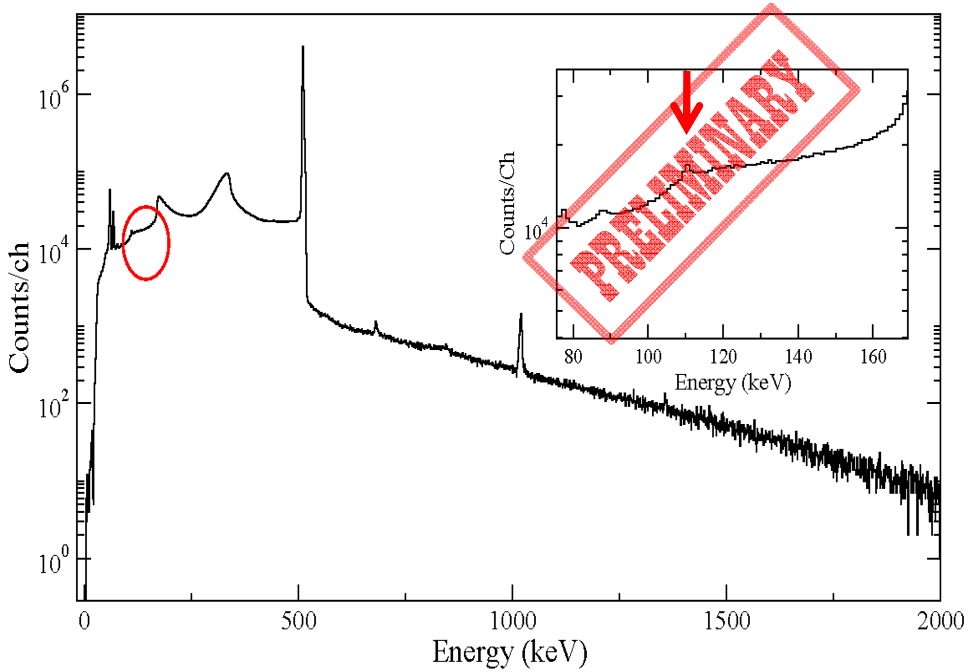
Where does our new preliminary datum fit?

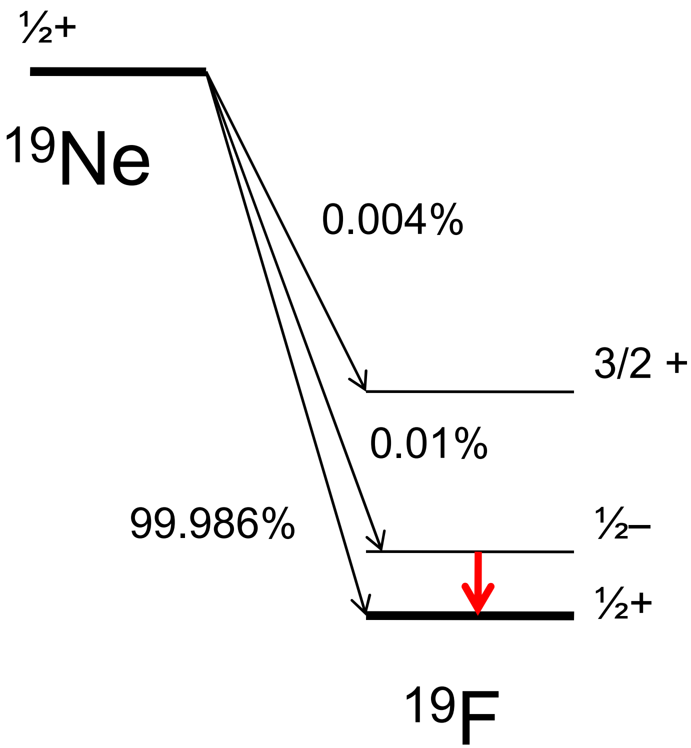
^{19}Ne lifetimes revisited



Branching ratio data from HPGe available

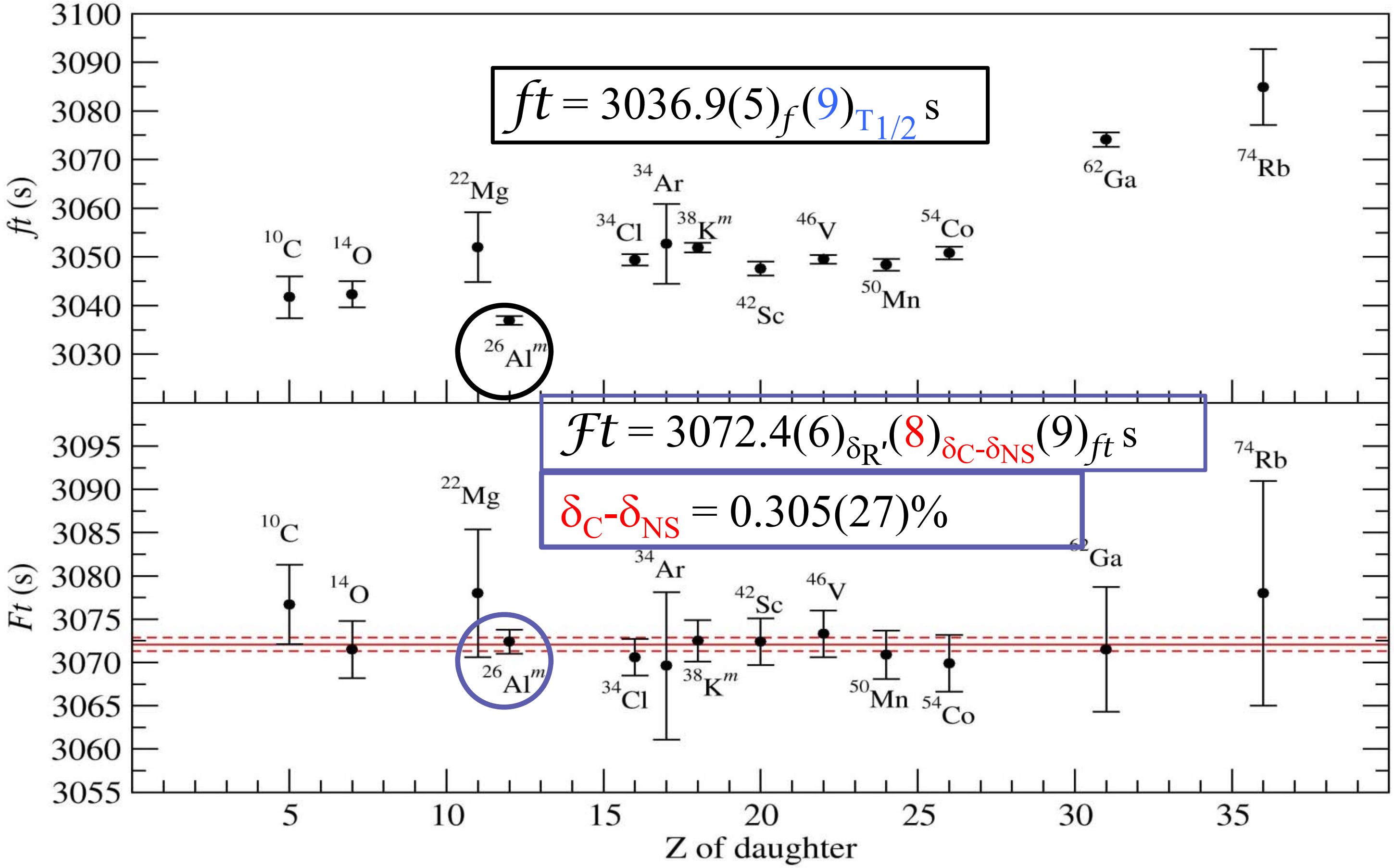
Branching Ratio





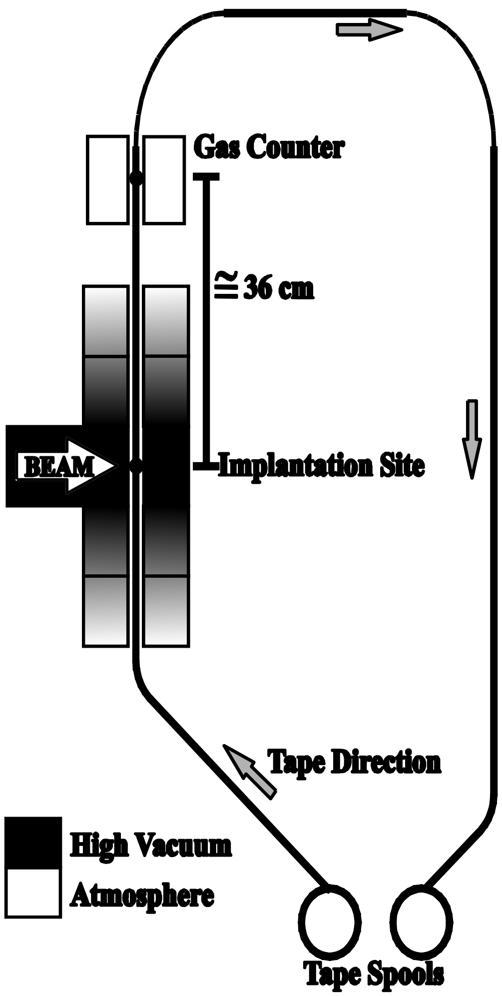
- Can use the symmetry of the array to clean this up.

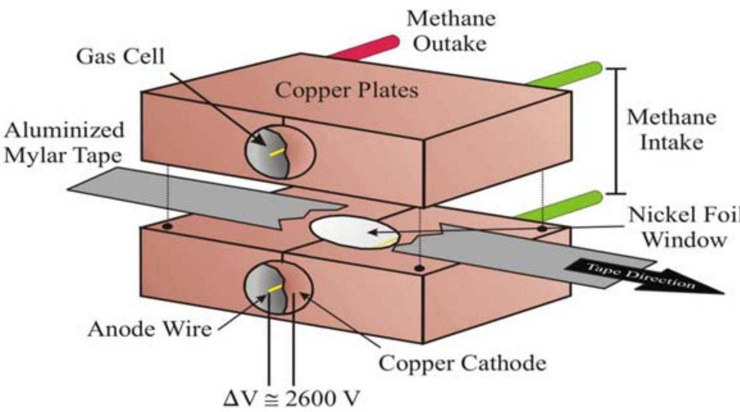
^{26m}Al and Nuclear Structure Corrections to $\mathcal{F}t$



J.C. Hardy and I.S. Towner, Physical Review C **79**, 055502 (2009)

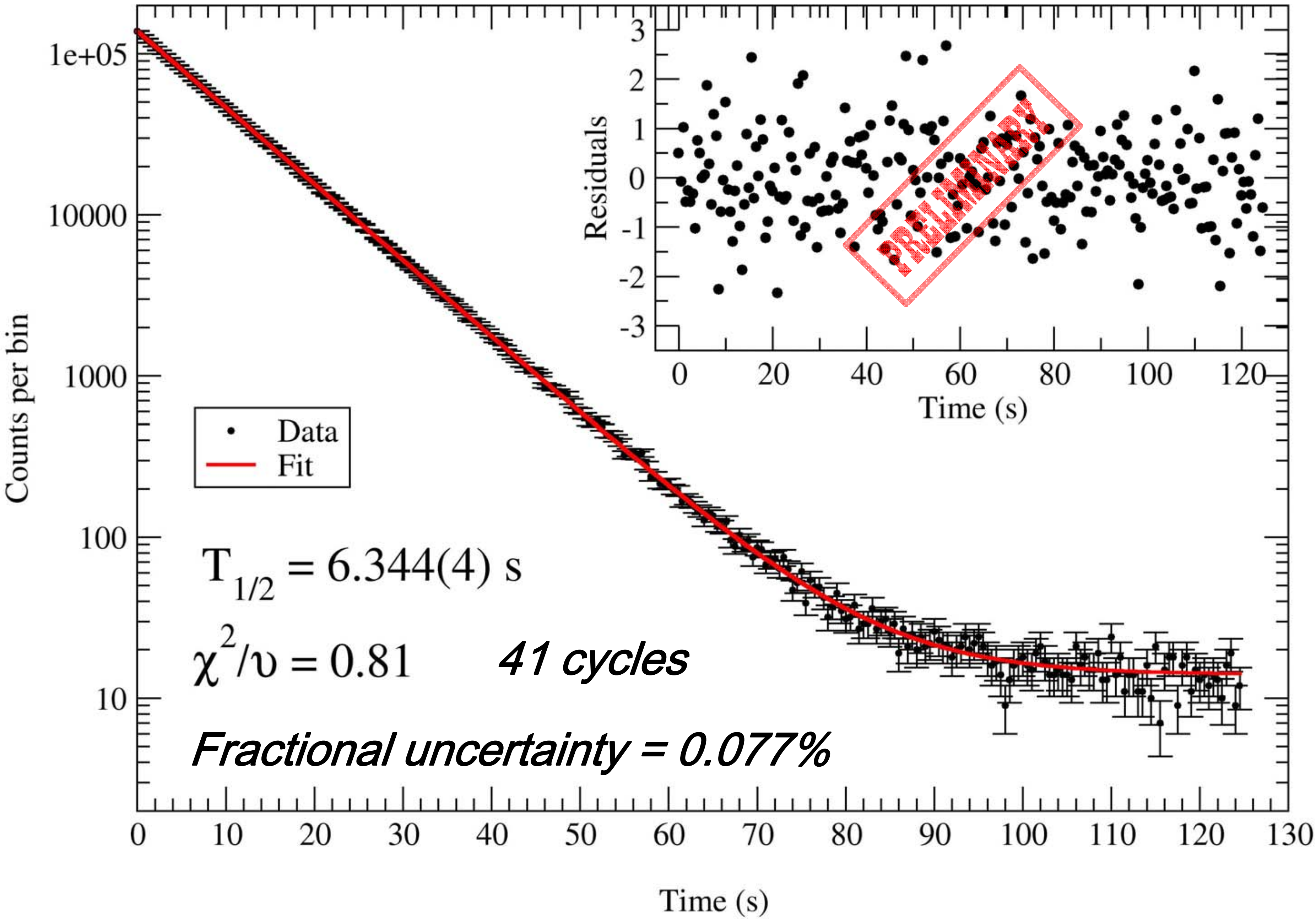
Beta-decay tape station

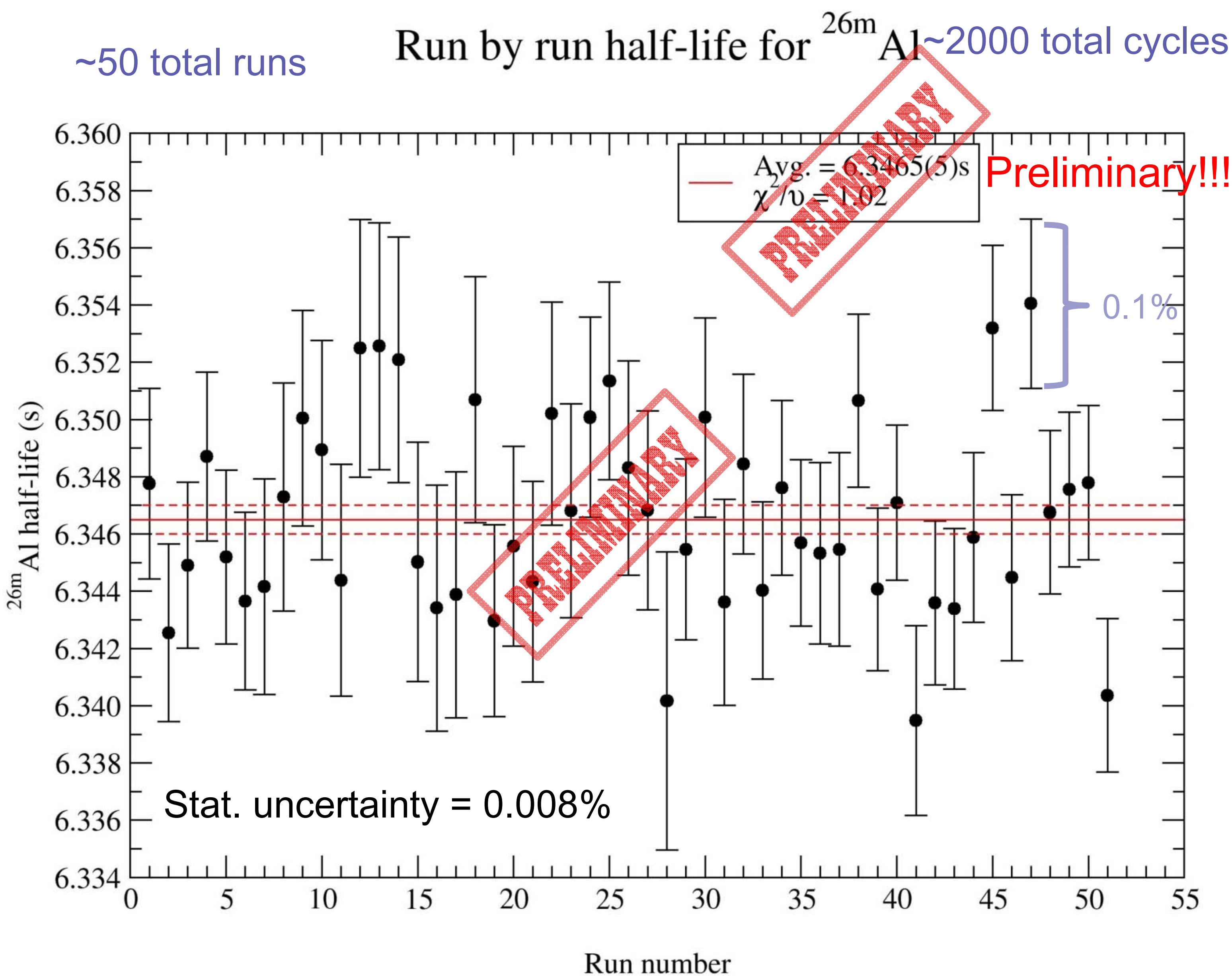




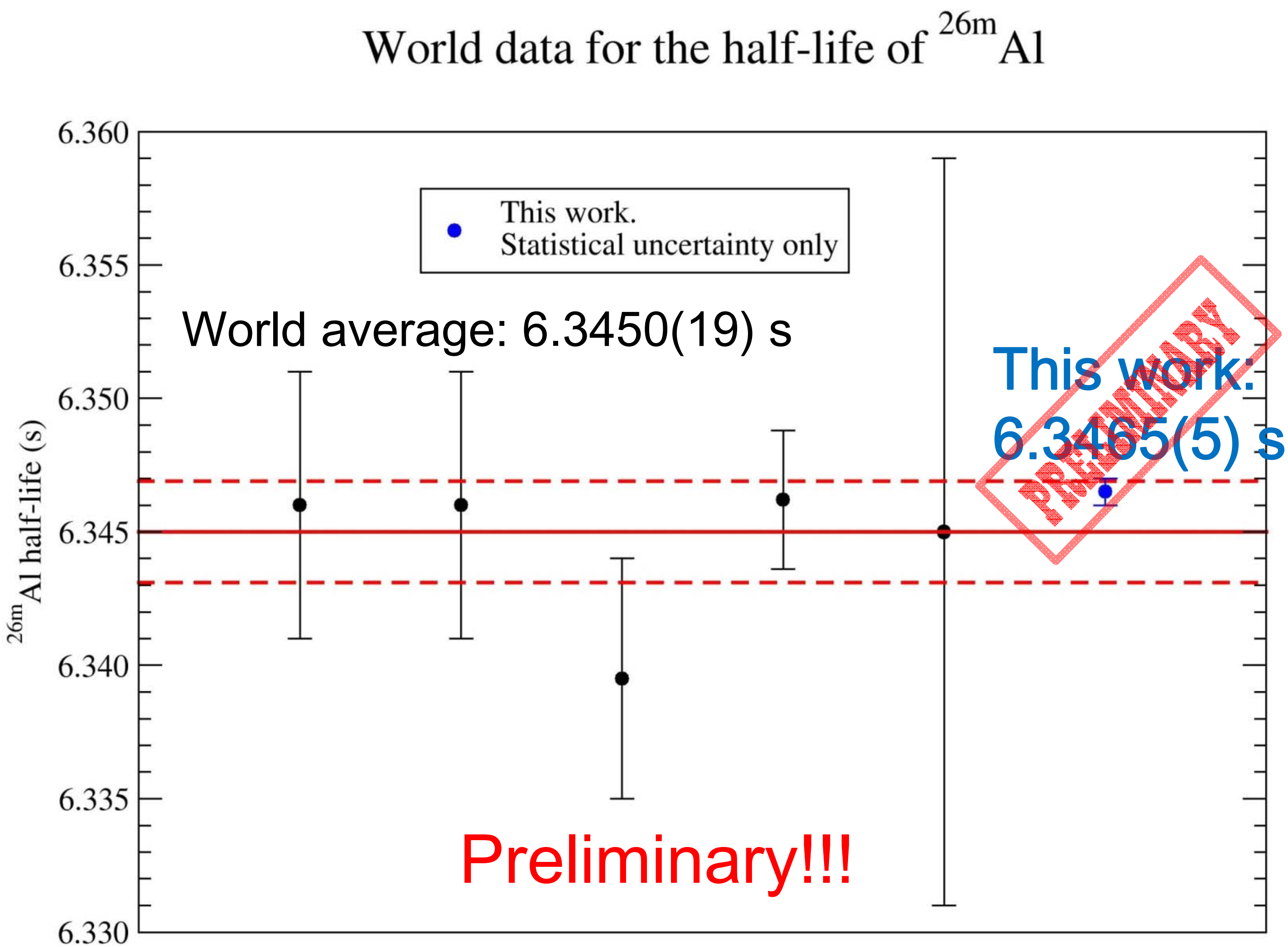
Run 5044

Discriminator = 100 V, Power supply = 2850 V, beam on/cool = 8s/32s

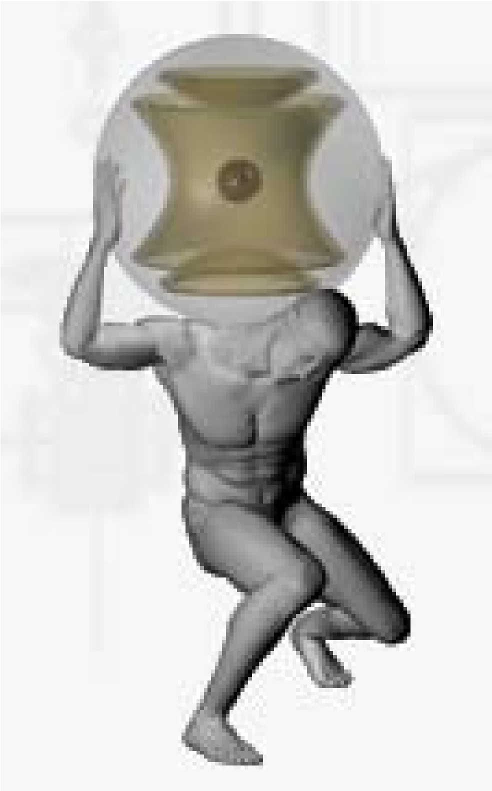




Run by run half-life for 26mAl
~50 total runs
~2000 total cycles
Avg. = 6.3465(5)s
χ2/υ = 1.02
Preliminary!!!
PRELIMINARY
PRELIMINARY
0.1%
Stat. uncertainty = 0.008%
26mAl half-life (s)
Run number
6.360
6.358
6.356
6.354
6.352
6.350
6.348
6.346
6.344
6.342
6.340
6.338
6.336
6.334
0
5
10
15
20
25
30
35
40
45
50
55

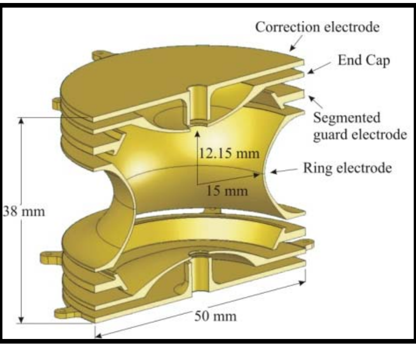


J.C. Hardy and I.S. Towner, Physical Review C **79**, 055502 (2009)

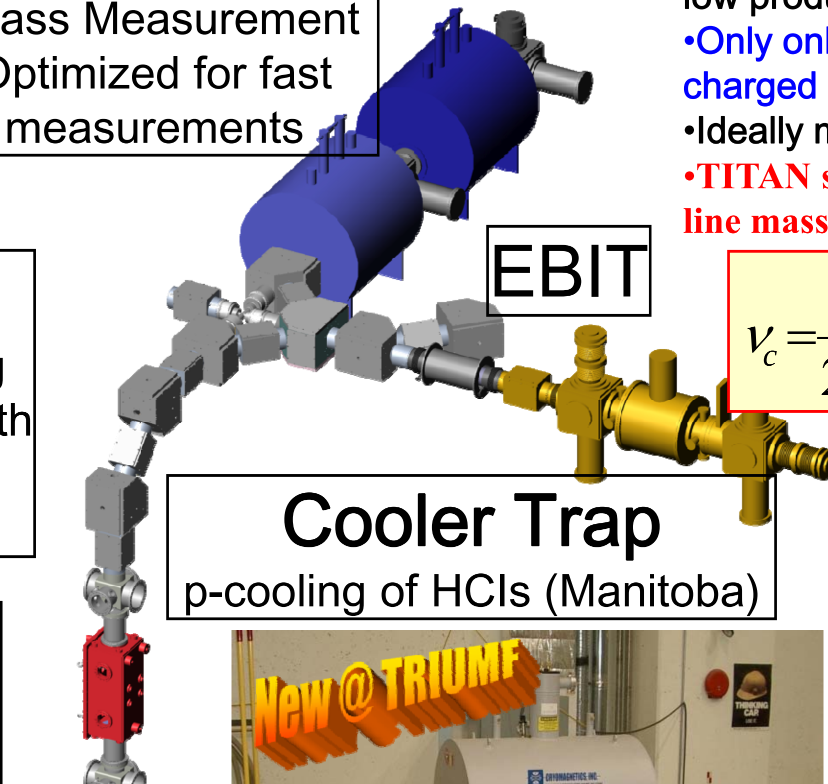


VERY NEW TITAN RESULTS

TITAN mass measurement system



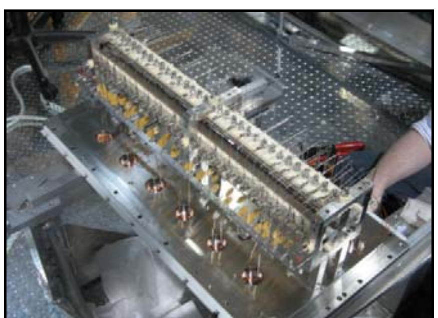
Penning Trap
Mass Measurement
Optimized for fast measurements



EBIT

RFQ
Cooling and Bunching
Sq-W driven system with He or H coolant reverse extraction

Cooler Trap
p-cooling of HCIs (Manitoba)



ISAC Beam

- Penning trap mass measurements on isotopes with short half-life $T_{1/2} \approx$ 10 ms and low production yields (≈ 10 ions/s)
- Only online spectrometer to use highly charged ions
- Ideally matched to on-line conditions
- **TITAN started April 2003 (NSERC), first on-line mass measurements carried out in 2007.**

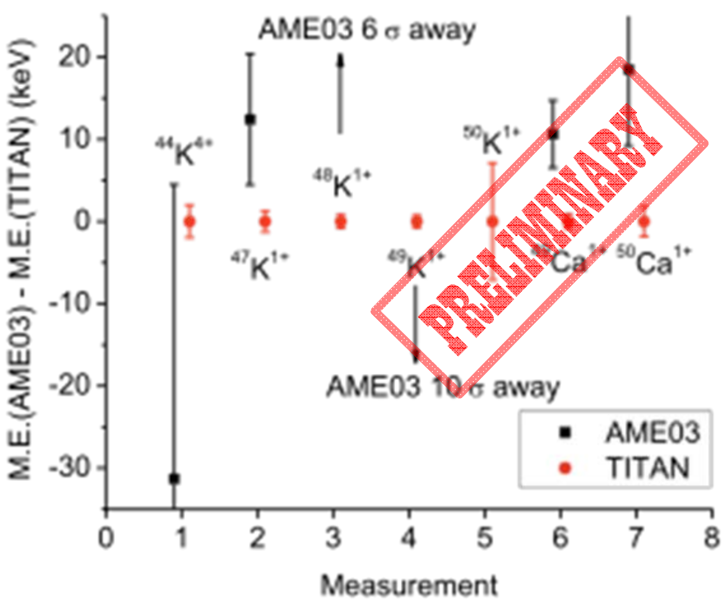
$$\nu_c = \frac{1}{2\pi} \cdot \frac{q}{m} \cdot B \qquad \frac{\delta m}{m} \approx \frac{m}{T_{RF} \cdot q \cdot B \cdot \sqrt{N}}$$

TRIUMF, McGill University, University of Muenster, MPI-K Heidelberg, GANIL, TU Munich, University of Windsor, Colorado SoM, Universite Paris-Sud, University of Manitoba, Yale, University of British Columbia, Simon Fraser University

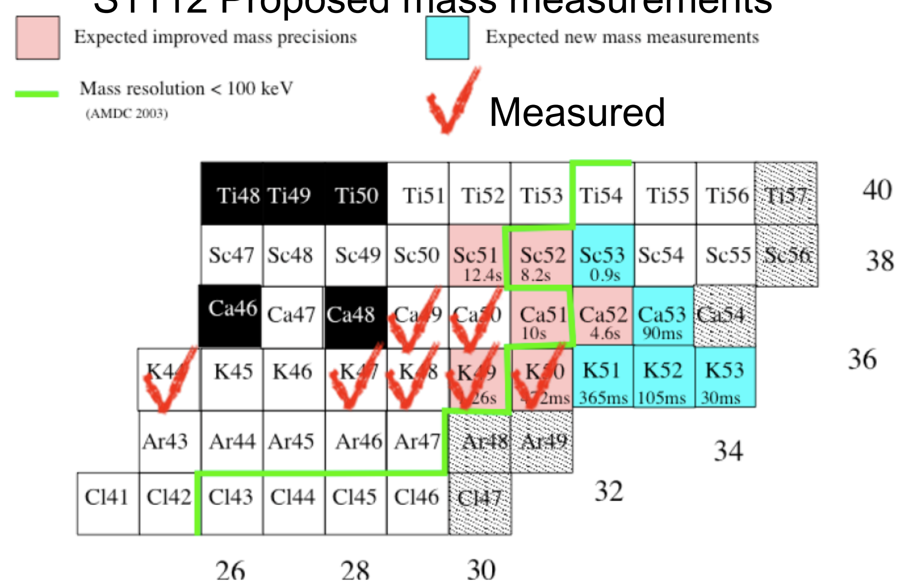
TITAN grad. students:
M. Brodeur (Wescott fellowship),
S. Ettenauer (Vanier & Killiam),
A. Gallant (NSERC fellowship),
V. Simon (DAAD fellowship),
T. Brunner (Villigst fellowship)

TITAN Masses – K Isotopes

- $^{44}K^{4+}$: First on-line mass measurement using charged bred ions from the EBIT
- $^{47-50}K^{1+}$ and $^{49,50}Ca^{1+}$: masses improved by factor of up to 100
- $^{48}K^{1+}$ and $^{49}K^{1+}$: deviations of 6 and 10 σ from AME03

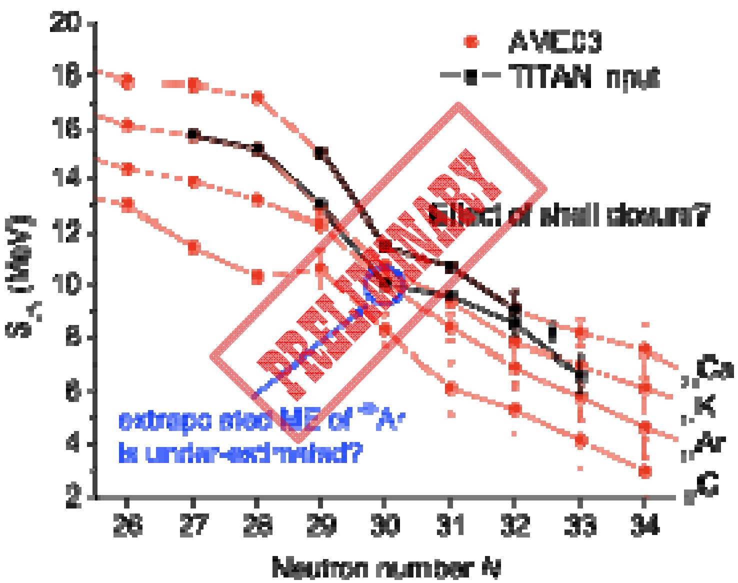


S1112 Proposed mass measurements



Results interpretation

Recall: $S_{2N}(Z,N) = M(Z,N-2) + 2{*}M_N - M(Z,N)$



Hint of shell closure at N = 32 for K?

Mass measurement of ^{51}K and ^{52}K would clarify the situation & would start to put constraint on N = 34

$S_{2N}(^{49}K) \sim S_{2N}(^{48}Ar)$: extrapolated value for ^{48}Ar under-estimated?

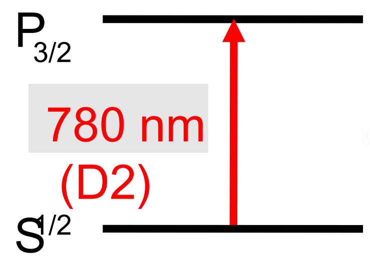
Mass measurement of ^{46}Ar and ^{48}Ar are needed

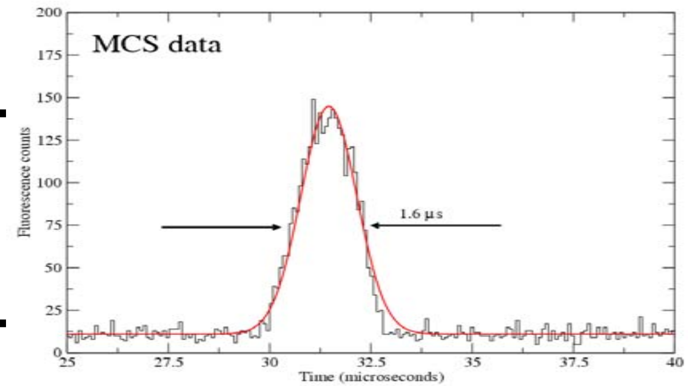
As the N-rich mass land scape get refined, more measurements are needed!

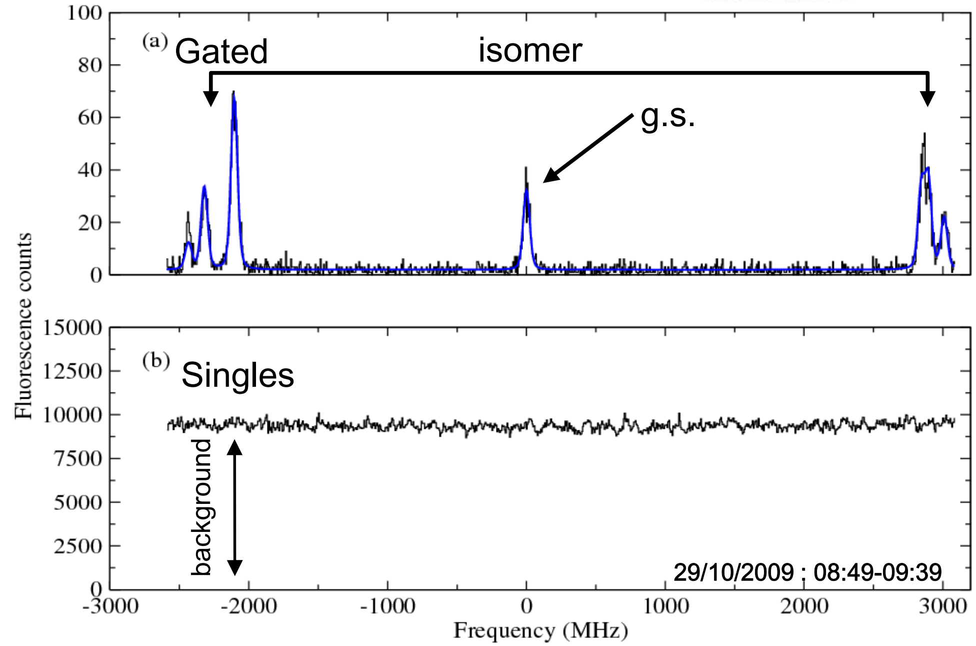
Together with measurement on ^{51}Ca and ^{52}Ca, it will refine S_{2N} values and start to constrain the various models

Co-linear spectroscopy w/ TITAN

- Demonstration with ^{78}Rb
- Inject up to TITAN RFQ
- Cool & bunch
- Push back down to collinear spectroscopy line
- 105 ions/bunch, 50 Hz cycle
- Move to ^{74}Rb early next year





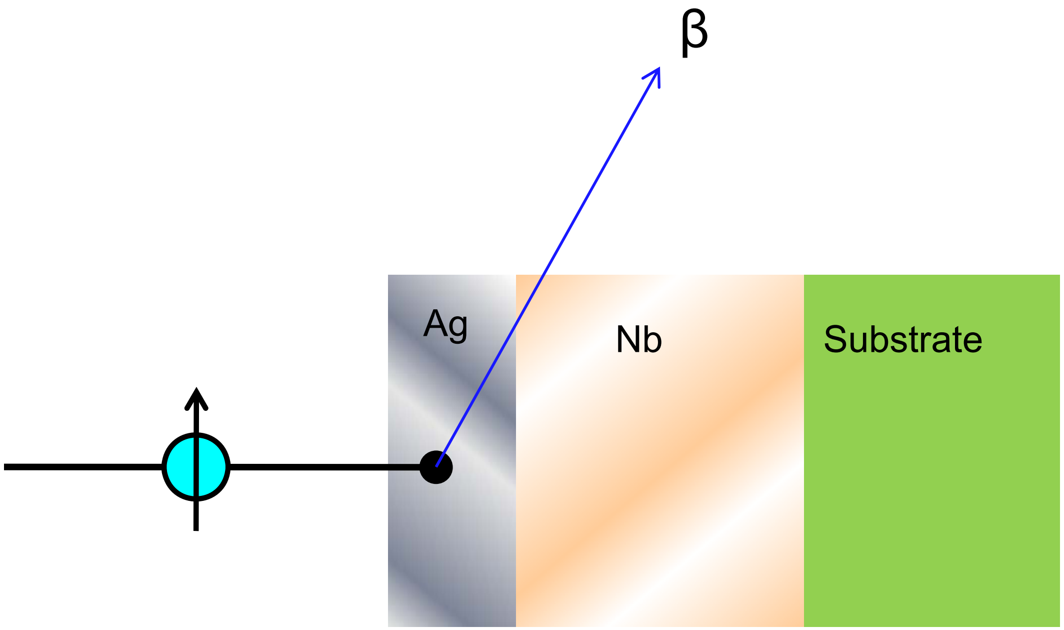


E. Mané, M. R. Pearson et al.

CONDENSED MATTER

β-NMR probes phase changes

- ^{8}Li beam, 10^{9}/s
- 30.6 keV
- Polarized
- Sample on HV platform to tune implantation depth
- Adjust temperature, B-fields, RF
  - New zero-field station for bNQR
- Detect ^{8}Li beta assymetry
- Ideal for senstive probing of thin films



Thin Film Ag on Nb Superconductor

- Thin Ag film on Nb surface
- Exhibits "Proximity Effect" Superconductivity
- How deep? Ongoing program
- G. D. Morris, W.A. MacFarlane, R. Keifl

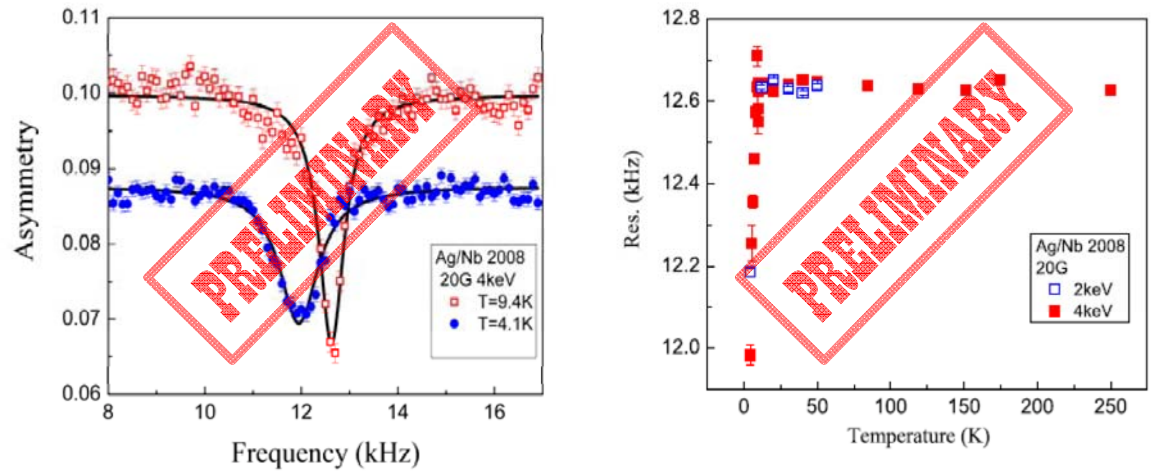


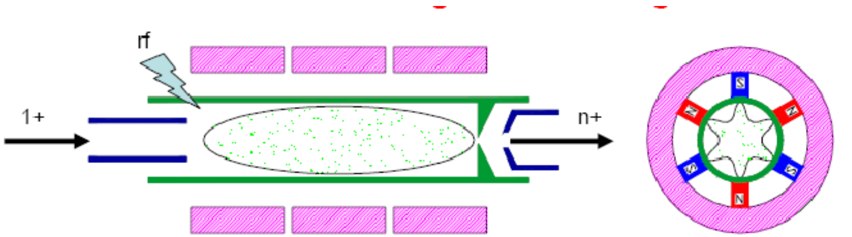
Fig. 1: Left: Resonance from ^{8}Li in Ag above and below the critical temperature T_{cNS} of the Ag(40nm)Nb(300nm) bilayer. Right: Resonance peak value versus temperature showing the diamagnetic shift below T_{cNS} in Ag.

THE FUTURE

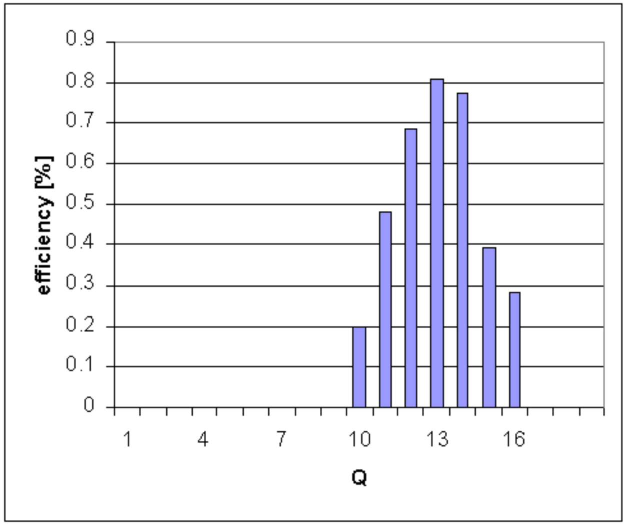
Status of the Charge State Booster (CSB)

- Requirements for acceleration:
- RFQ: M/Q <30, DTL : M/Q < 6

  presently limited to A < 29
- ECRIS used to breed high-charge state ions (no further stripping)
- April 2010 : Beams with A > 29 can be added to the inventory

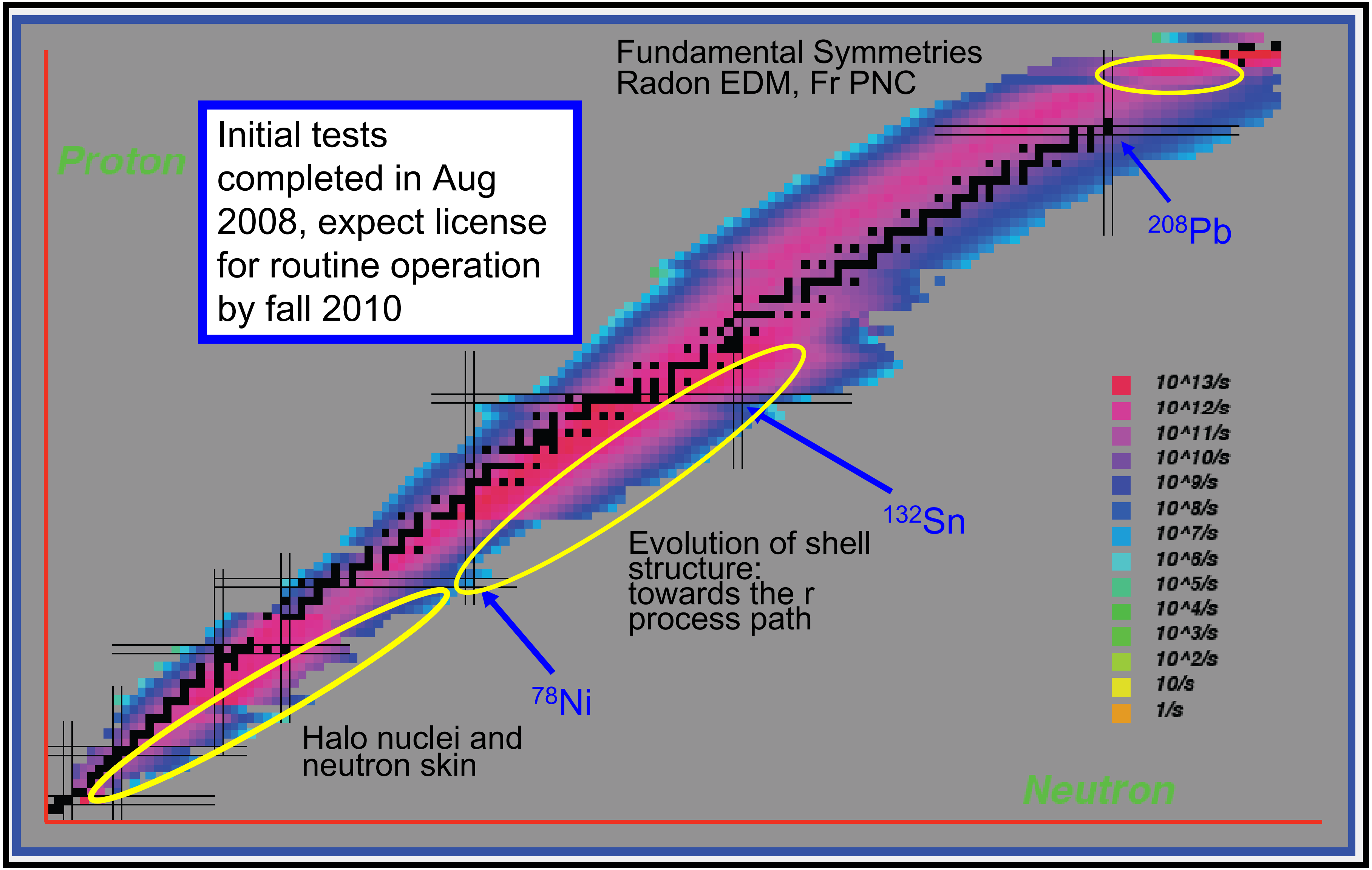


^{80}Rb charge state distributions

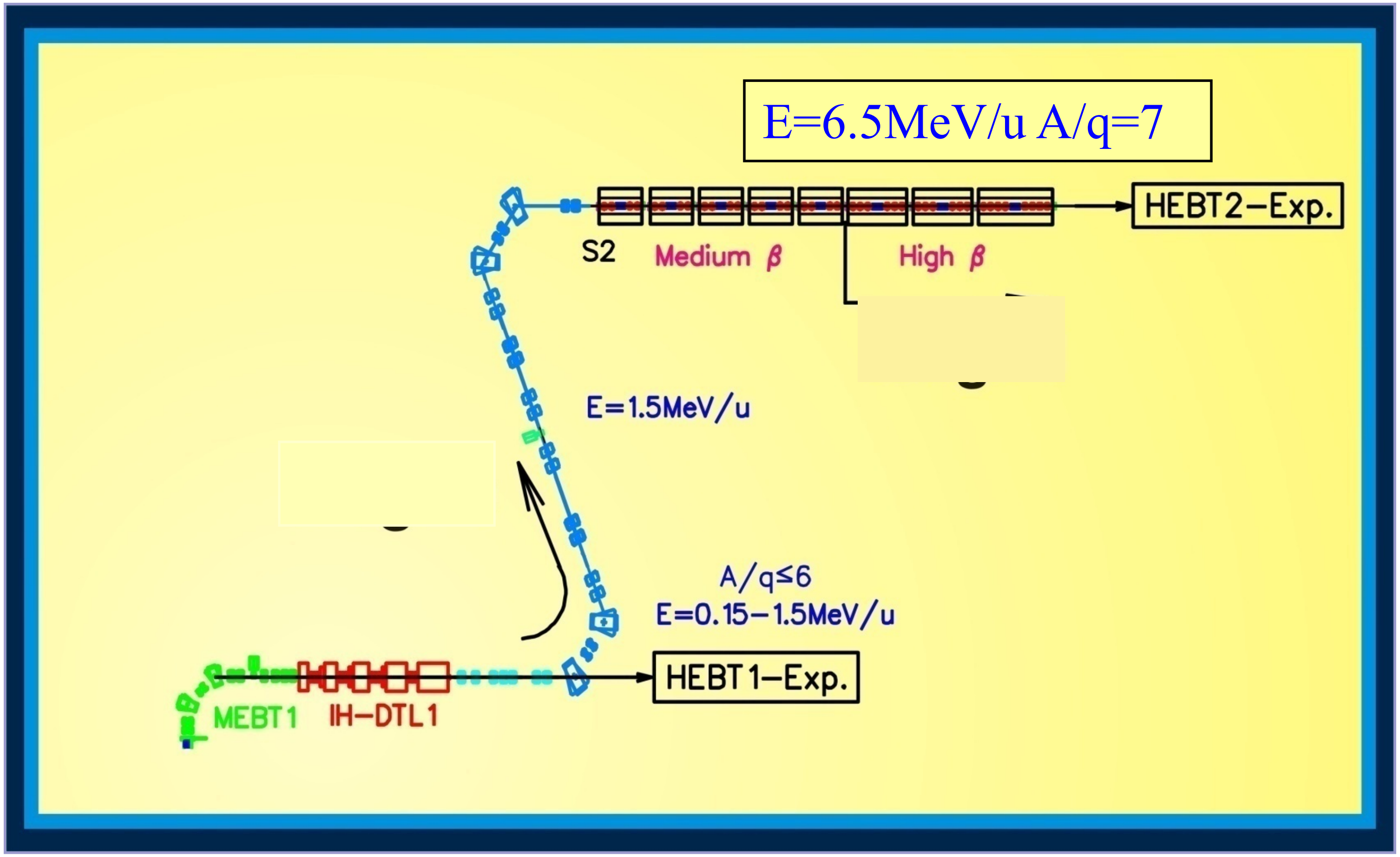


$^{80}Rb^{14+}$ accelerated Nov 2008

10 μA of 500 MeV protons on ^{238}U (22 g/cm^2)

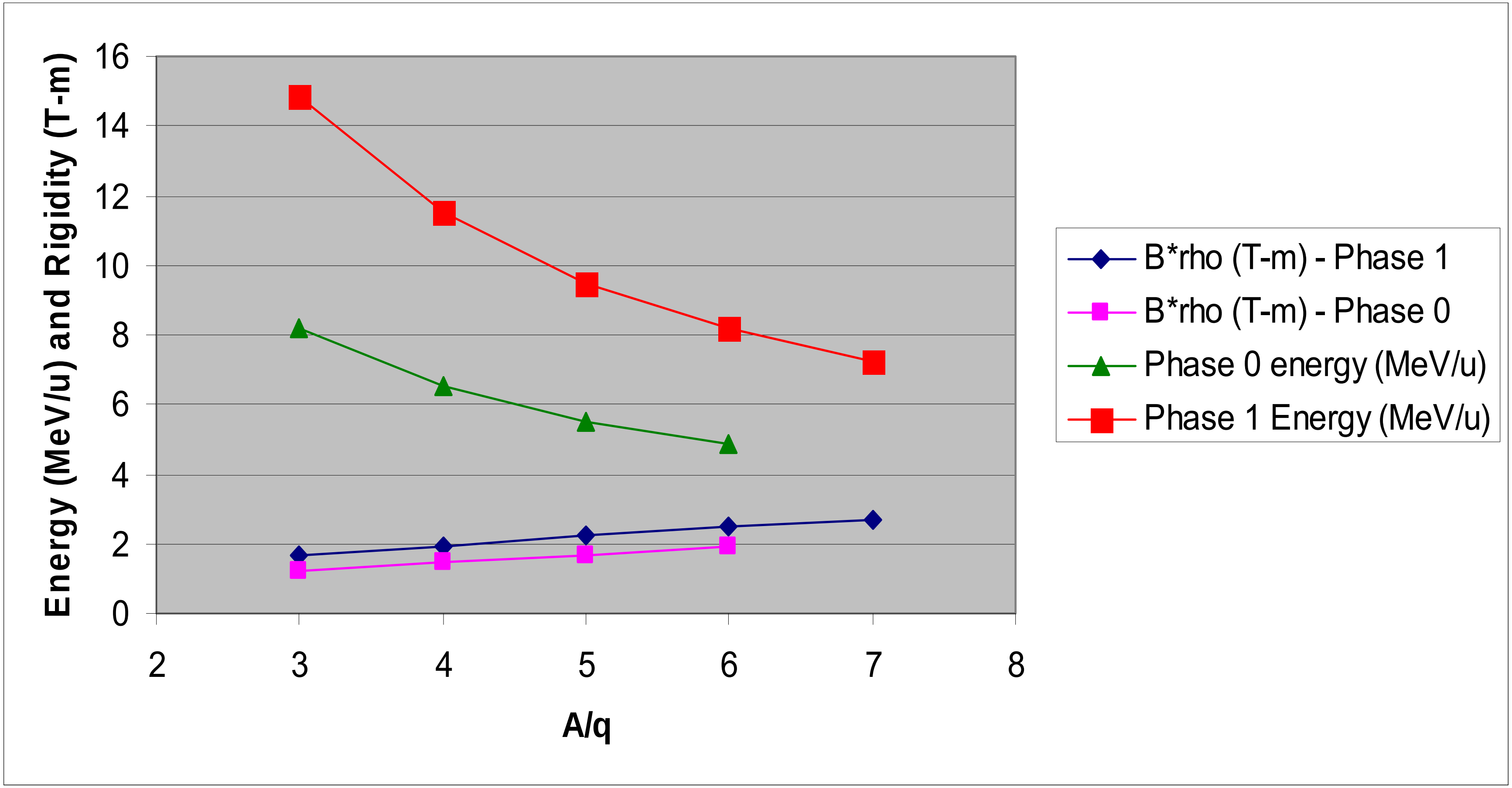


ISAC-II: Phase-1 High beta cavities

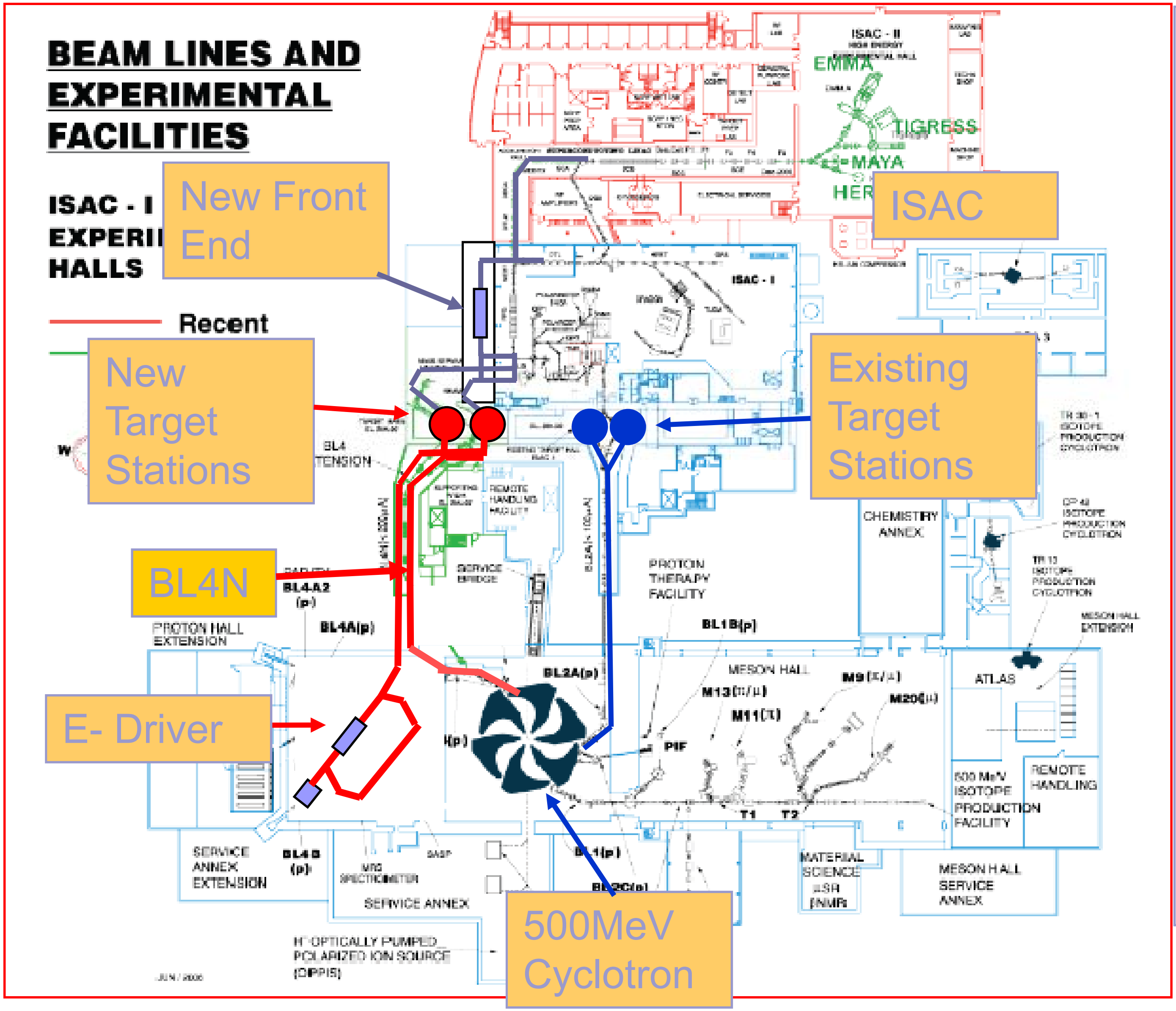


- the addition of 20 high- beta' (β=0.11) quarter wave cavities housed in three cryomodules and add an additional 20MV.by the end of 2009
- the modules are being installed now and will be available for experiments in spring 2010.

Final Energy and Rigidity



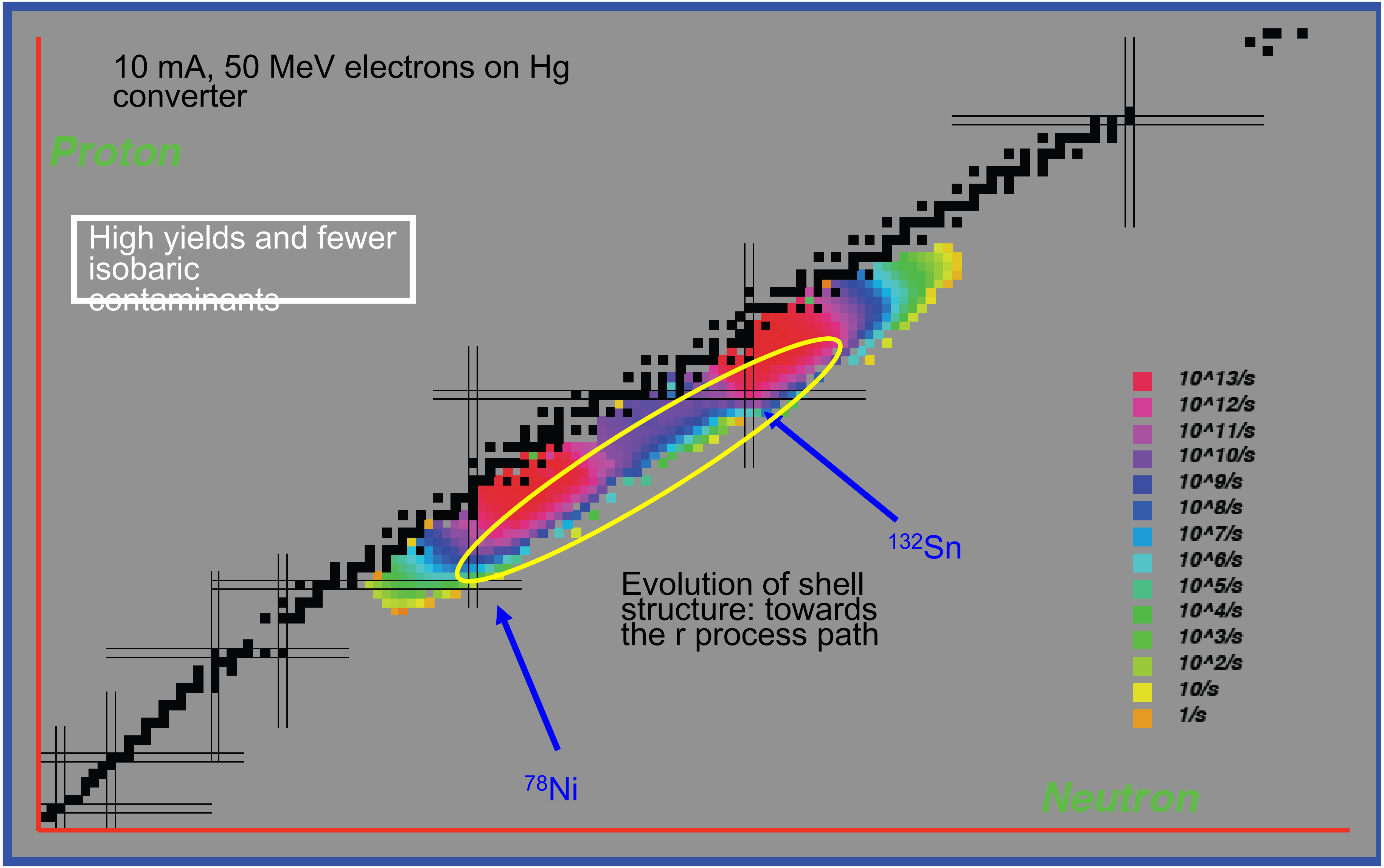
TRIUMF: ISAC Five Year Plan



Proposal:

- BL4N is proposed to deliver 500MeV protons to two target stations for beam production and an additional RIB station for development
- Take advantage of the shielded and unused proton hall to add an electron driver to supply electrons to the new target area via a separate beamline;
- Develop new ISAC front end to permit three simultaneous RIB beams (two accelerated).

Photo-fission of ^{238}U (7 g/cm^2)



Many many thank yous

Apologies to many people I couldn't get to – TRINAT, BAMBINO, fast timing, Rn-EDM, and astrophysics programs (esp. J. Behr, D. Jenkins, C.-Y. Wu, D. Cline, P. Garrett, K. Green, C.E. Svensson, T. Chupp, C. Ruiz, B. Davids, D.G. Jenkins and many more)

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Thanks to all visitors and collaborators who have helped make the TRIUMF-ISAC science program as vigorous as it is

And thank you to the organizers for letting me come here and tell you about it

Congratulations to the ISOLDE community on HIE-ISOLDE

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